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Earth Physics Branch

Direction de la physique du globe

**CANADIAN
GEOPHYSICAL
BULLETIN**

**BULLETIN
CANADIEN
DE GÉOPHYSIQUE**

Volume 33

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SEP 25 1981

GEOLOGICAL SURVEY
COMMISSION GÉOLOGIQUE

**December/décembre 1980
Ottawa, Canada**

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Volume 33

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 1980
Ottawa, Canada**

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INTRODUCTION

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

The chapters on Aeronomy and Volcanology, missing from the 1979 edition, have been included again this year. The present edition is weak on coverage of applied geophysics. There is no chapter on Engineering Geophysics, although many projects which could be classified under this heading appear in the Mining Geophysics chapter. For the next and subsequent editions coverage of the important area of applied geophysics will be extended and improved.

The Editor wishes to thank all of his colleagues who have cooperated in the work of gathering material for the Bulletin. In particular, the work of the compilers of chapters is appreciated for the time and effort they have put into the manuscripts for their chapters. The editor has attempted to spread any deletions which were necessary to conform to space requirements as fairly as possible throughout the various chapters. A set of guidelines to aid compilers and individual contributors of reports is in preparation. It is hoped that these will be an aid in determining the extent and degree of detail to which reports on individual projects should go. It is also a pleasure to acknowledge the assistance of Mrs. S.D. Fay at the University of Manitoba and Mr. E.B. Manchee and Mrs. J. Breton in the Earth Physics Branch, Department of Energy, Mines and Resources.

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 of back issues should request these from:

Publications
Earth Physics Branch
Department of Energy, Mines & Resources
1 Observatory Crescent
Ottawa, Ontario
Canada
K1A 0Y3

There is no charge for the Bulletin, but the Canadian National Committee appreciates receiving similar national or international reports in exchange.

D.H. Hall
Editor

INTRODUCTION

Le Bulletin canadien de géophysique est un rapport annuel des recherches, des développements et des services géophysiques dans l'industrie, le gouvernement et les universités au Canada. Le but principal est d'établir un dossier permanent des chercheurs actifs, de leurs travaux et des publications de l'année. Il est fait une brève mention des résultats de ces recherches, cependant ces résultats ne sont pas donnés en détail, puisqu'on peut se renseigner à leur sujet en consultant la liste des ouvrages de référence. Ce bulletin, depuis 1974, est publié sous la direction du Comité national du Canada de l'Union géodésique et géophysique internationale.

Les chapitres sur l'aéronomie et la volcanologie qui n'ont pas paru dans l'édition de 1979 ont été réintégrés cette année. La présente édition touche à peine le domaine de la géophysique appliquée. Il n'y a aucun chapitre sur la géophysique technique, bien que plusieurs travaux qui auraient pu être classés sous ce titre apparaissent dans le chapitre sur la prospection géophysique. Dans la prochaine édition et dans les suivantes, cette branche importante de la géophysique appliquée sera traitée plus en profondeur.

Le rédacteur en chef désire offrir un témoignage de reconnaissance à tous ceux de ses collègues qui ont contribué aux recherches pour la publication de ce bulletin, en particulier les compilateurs des chapitres pour le temps et l'effort consacrés à la rédaction de leurs chapitres. Il a essayé, de façon aussi judicieuse que possible, de répartir sur tous les chapitres les suppressions qui étaient nécessaires, vu l'espace disponible. Un ensemble de lignes directives visant à aider les compilateurs et les particuliers qui collaborent par leurs rapports est maintenant en préparation. Ces lignes directives, on l'espère, seront un outil pour déterminer le degré de minutie à accorder aux rapports publiés sur les différents travaux. C'est avec non moins de reconnaissance que nous mentionnons les noms de Mme S.D. Fay, de l'Université du Manitoba, de M. E.B. Manchee et de Mme J. Breton, de la Division des sciences de la Terre du ministère de l'Energie, des Mines et des Ressources, pour l'aide qu'ils ont apportée.

Ce bulletin est publié et distribué aux lecteurs du Canada et de 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 et le Conseil canadien des sciences de la Terre. Les demandes pour obtenir un exemplaire des numéros précédents doivent être adressées à:

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

D.H. Hall
Rédacteur en chef

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Cat. No.: M74-37/33

ISBN: 0-662-51514-5

ISSN: 0068-8819

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N° de cat.: M74-37/33

ISBN: 0-662-51514-5

ISSN: 0068-8819

I (A) GEODESY

Compiled by: D.E. Wells

1. Introduction
2. Geodetic Survey of Canada
3. Earth Physics Branch (Gravity and Geodynamics Division)
4. National Research Council (Division of Physics)
5. Bedford Institute of Oceanography (Canadian Hydrographic Service and Metrology Division)
6. Canadian Hydrographic Service
7. Université Laval (Département de Géodésie et de Cartographie)
8. University of New Brunswick (Department of Surveying Engineering)
9. York University (Department of Physics)
10. University of Toronto (Erindale Campus)/Marshall Macklin Monaghan, Limited
11. University of Calgary (Surveying Engineering Division)
12. McElhanney Surveying and Engineering Limited
13. Sheltech Canada
14. Bibliography

1. Introduction

This was a year of change and growth for geodesy in Canada. Research on advanced techniques such as Doppler, Inertial and VLBI continued with the cooperative approach and joint projects seen in the past. This year initial work on the NAVSTAR/GPS technique was begun by several groups. Canadian geodesists have demonstrated mobility between government, industry and universities during the past few years, with the result that new research programmes began to bear fruit this year, as evidenced by the longer list of contributors to this chapter. The manuscript of a new textbook "Geodesy: The Concepts" by P. Vanicek and E.J. Krakiwsky was submitted to North Holland during the year. The Canadian Institute of Surveying published both the proceedings of the Second International Symposium on problems related to the Redefinition of North American Vertical Geodetic Networks, held in Ottawa in May, and a set of papers prepared for Geodetic Seminars held in Edmonton, Vancouver, Calgary and Toronto on the topic "Impact of Redefinition and New Technology on the Surveying Profession".

2. Geodetic Survey of Canada

(a) Horizontal Positioning

Satellite Doppler positioning was used in 1980 to strengthen the basic network, to increase its density and to provide control for future federal and provincial secondary surveys. Eighty positions were occupied in the following regions: Saskatchewan (21), Manitoba (12), Ontario (14) and Quebec (33).

The first-order network was densified in the vicinity of Saskatoon, Saskatchewan, by trilateration, and in the Sault Ste. Marie area of Ontario first-order and federal secondary networks were strengthened by angle and distance measurements.

Seven calibration baselines were measured or remeasured by Mekometer to check pier stability in Scarborough and Burlington, Ontario, Edmonton, St. John's, Summerside, Bathurst and Port Hawkesbury.

Astronomic observations for azimuth control were made in various locations in preparation for the 1983 NAD readjustment. Ten Laplace azimuth observations were made, 3 in Alberta, 1 in Manitoba, 2 in Quebec and 4 in Labrador. An additional 8 lower-order azimuths were observed at locations in Ontario (4) and Manitoba (4). Astronomic observations for latitude and longitude were made at 42 existing stations to determine the deflection of the vertical for geoid studies, 17 in British Columbia, 3 in Alberta, 6 in Manitoba, 8 in Ontario, 6 in Quebec, and 2 in Newfoundland and Labrador.

The Inertial Survey System was used to establish second-order control for mapping and for densification in Nova Scotia, Manitoba, Saskatchewan and Alberta. Minor ISS projects were also undertaken in Ontario, Victoria Island and Quebec. Approximately 13,500 km of ISS traversing was accomplished in 1980.

(b) Vertical Positioning

Approximately 4,600 km of first-order levelling was completed in 1980. This included about 2,500 km of relevening for network maintenance. Major new levelling projects were undertaken in Quebec and along the Canol Road, N.W.T. Special-order levelling projects were completed along the Welland Canal, Ontario, and in the Baie-St. Paul area of Quebec.

Lower-order levelling was used to provide control for ISS vertical traversing in Alberta and Ontario. Additional control for mapping using the Ground Elevation Meter (GEM) was provided in Quebec, Baie Comeau and Mont Laurier areas and also in Southern Ontario. Miscellaneous surveys were undertaken in the Arctic Islands, Northern British Columbia and Newfoundland to strengthen existing surveys and to support mapping programmes.

(c) Data Processing and Banking

Agreement was reached with NGS on preliminary datum parameters for the NAD83 adjustment. In preparation for updating our test adjustment to complete the data evaluation, the automated file of primary framework data has been reprocessed and verified. Work is also continuing on some aspects of the development of the Helmert block adjustment software.

In regard to the effective exchange of secondary and lower-order horizontal control between federal and provincial agencies, network evaluation was continuing at Geodetic Survey. Data for about 19,000 stations have been automated and some 16,000 evaluated.

Major readjustment of some 25,000 secondary horizontal control stations was completed in parts of Newfoundland, Nova Scotia, Baffin Island and the Queen Charlotte Islands. Readjustment of about 1,200 vertical control points was completed in Quebec-Labrador and the Arctic Islands.

Computer programme maintenance continued and included modifications to Doppler processing, the consolidation of plotting programmes for conventional, Doppler and ISS networks, and an out-of-core version of programme LEVELOB.

Major redesign of the National Geodetic Data Base (NGDB) was undertaken to improve the storage and retrieval of data and to facilitate participation by other federal and provincial agencies. Positional control survey information for 105,000 stations has now been transferred from the old data base to the new NGDB.

(d) Research Activities

In support of the 1980 Redefinition of North American Horizontal Geodetic Networks geoid undulations and deflections of the vertical were predicted at all stations of the primary triangulation network. The method employed varied according to the nature of the topography and the data sets which were available. For the mountainous areas a combination of digital terrain data at 1 km spacing and available point gravity observations were used in addition to the astro-geodetic deflections and GEM10B geopotential model. Documentation of the least squares collocation software employed in this work was begun.

Techniques for modelling the distortions in geodetic networks were further developed using both complex polynomials and least squares collocation approaches.

An international symposium on problems related to the redefinition of North American vertical geodetic networks was held in Ottawa in May. The proceedings, 978 pages, were published in August and provide the most current and complete information on this topic. The use of solar radiation data for predicting vertical temperature gradients was investigated in-house. Refraction and gravity related corrections were computed and applied to several levelled lines in Canada.

Several aspects of inertial positioning were investigated. Covariance analysis software developed at UNB was further refined and converted to the EMR computer. Close liaison was maintained with a contract researcher at U. of Calgary. Assistance was provided to U.S. National Geodetic Survey in planning for field tests leading to the development of specifications and standards for inertial survey systems.

Activities related to the U.S. Navy TRANSIT satellite navigation system included the preparation of guidelines and specifications for satellite Doppler surveys, the reduction of 1979 test data using precise ephemerides and an assessment of the CMA-761 and JMR4A microprocessor controlled receivers.

Development of an automatic star transit detector attachment for a Wild T-4 theodolite was continued. Tests of biodegradable materials for aerial survey targets were carried out in cooperation with U. of Toronto. Motorized levelling techniques currently practised in Europe were investigated for possible application in Canada. In the Yukon territory levellers were transported by helicopter between set-ups on difficult stretches of the line from Ross River to Norman Wells. Roads have yet to be built in most parts of the north.

Contracts for the study of signal processing techniques and mathematical models appropriate for geodetic applications of the Global Positioning System were given to Canadian Marconi Company and UNB respectively.

3. Earth Physics Branch (Gravity and Geodynamics Division)

(a) Polar Motion Studies

Satellite doppler and optical astronomical (PZT) observations from the observatories near Ottawa, Ontario and Calgary, Alberta have continued as part of the international earth rotation and polar motion services (BIH, IPMS, DPMS). Satellite doppler tracking of navigational and geophysical satellites has been carried out by TRANET stations controlled by a mini-computer distributed network facilitating unattended data acquisition, verification and real-time transmission to the DMAHTC Satellite Polar Monitoring Center. In addition to precise orbit and pole

position determinations at the central processing facility a new software package has been developed at the Earth Physics Branch to evaluate satellite orbit biases over Canada and pole position corrections based on data from the Canadian TRANET stations. Preliminary results have been obtained for data on one satellite collected during 1979 and the analysis is continuing.

PZT observations have been evaluated on a daily basis and the results transmitted weekly to BIH and IPMS. Annual summary reports on the PZT time and latitude observations in 1978 and 1979 have been published in the Geodynamics Series Bulletins Nos. 71 and 72.

Development of a geophysical long baseline interferometry (LBI) system for monitoring earth rotation continued in cooperation with York University. Three experiments on the A.R.O.-D.R.A.O. baseline have taken place during 1980 using dual frequency for radio astronomy and ANIK-B satellite communication to monitor local oscillator phase. Preliminary results indicate unprecedented precision of about 100 picoseconds in local atomic standard synchronization over the 3074 km baseline and UT1 determination at 0.3 ms level.

(b) Sea Ice Motion

LOREX 79 satellite doppler observations have been completely reprocessed using a new dynamic satellite positioning software package resulting in significantly higher data recovery and much improved ice camp positions. Analysis of differential sea ice drift has been carried out to evaluate strain of pack ice in the vicinity of the North Pole.

4. National Research Council (Division of Physics)

(a) Photogrammetric Research Section

Research has been continued in the field of refraction and its application in astronomy, 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 0.9 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 until 1980. In 1980, there was a slight increase in the speed of rotation of the earth, and a leap second will not be necessary until sometime in 1981.

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, CsV1 A, B and C, have been built, and will improve further the reliability and stability of the NRC time scale.

In July 1978 two-way satellite time transfers began between NRC and Observatoire de Paris using the Symphonie satellite, and between NRC/NBS and NRC/USNO using the Hermes satellites. These experiments have shown

that precision of a few nanoseconds can be attained in comparing times, and that the frequencies of the time scales can be compared internationally to 1×10^{-14} . The Hermes experiment lasted one year, but the Symphonie time transfer is continuing, and once a week transfers will be made in 1981. The PTB laboratory joined the experiment in February 1980 to give a three way comparison between Canada, France and Germany (FRG).

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

(a) Integrated Navigation

Development of the BIONAV system, which integrates Transit Satnav, ranging Loran-C and log/gyro has been extended to operate a flatbed plotter, and to process bathymetry and output Eotvos correction on line. Work with the Atlantic Geoscience Centre in integrating skywave Loran-C with Transit will lead to incorporating a skywave routine in BIONAV to relieve the present necessity for a 24 hour navigation watch.

(b) Navstar

A contract study done at UNB has shown that the limited initial deployment of six Navstar satellites can usefully augment ranging Loran-C in Baffin Bay, an area which presents a tough problem for precise navigation. A joint programme is being developed to exploit this, using BIONAV as the basis of the integration.

(c) Loran-C phase prediction and performance

Calibration observations have been made in an additional five selected areas between the Bay of Fundy and Placentia Bay, Newfoundland. These will adjust the regular grid of theoretical phase predictions now used in chart construction. The data will also be analyzed to explore land effect, particularly in the inshore zone. Land observations by calibration van extending from the west coast to the east coast of Newfoundland showed a significantly higher than normal land resistivity. This will result in larger land-path corrections for southward transmissions from the new Labrador transmitter which is scheduled to be operational in 1983.

Little is known of Loran-C performance in the Arctic, and oil development may shortly require its deployment there. In September 1980 the Pacific and Atlantic regions of the Hydrographic Service, with participation from the Canadian Coast Guard, observed Loran-C transmissions from two 150 ft. Decca towers at six points distributed around the Mackenzie Delta area of the Beaufort Sea. Performance was 100% at 300 NM range over sea water with a small amount of drift ice, but cycle selection deteriorated markedly with land path implying that even under "summer" conditions permafrost affects the pulse shape. A follow-up test next April will explore performance over solid sea ice, and permafrost without a thawed surface layer.

(d) Tides

Vertical tidal measurement and analysis is being undertaken both on the continental margin and in the deep ocean.

Work is being done under contract to develop a sophisticated acoustic telemetry link to transmit tidal data from a bottom-mounted pressure gauge to a remote site. This is in the final construction stage.

(e) Hydrographic Development

Software interactive editing has been developed and is now in operation in both field and office. In the field, depth and position data are edited on an HP 2100 minicomputer. In the office, both line and point cartographic data are digitized, merged, and edited on the main Cyber computer.

Microprocessor navigator units are now in use on board sounding launches to guide the coxswain along sounding lines, independent of the direction of the position lines (a limitation of earlier left/right indicators). The presentation is based on the blind-approach instruments in aircraft.

6. Canadian Hydrographic Service

(a) Tides, Currents and Water Levels Division

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

(b) Nautical Geodesy Section

The horizontal control adjustment programme, designed to facilitate the transition from the 1927 NA datum to the 1983 Geocentric datum, has advanced with the completion of the Nova Scotia control networks. All adjusted stations are utilized to update the horizontal control data bank and List of Lights data file. An adjustment programme is presently being structured for the area from Cornwall to Brockville, Ontario, as a first step to addressing problems concerned with the charting of common boundary areas between Canada and U.S.A.

Nautical Geodesy participated in several Loran-C calibration exercises, assisting in collecting and analyzing the data, and providing parameters for navigational charts.

7. Université Laval (Département de Géodésie et de Cartographie)

Le projet sur le gyrocompas suspendu a été complété. Une théorie originale du gyrocompas suspendu a été développée et a permis de décrire d'une façon plus précise et plus complète les mouvements auxquels ce dernier est soumis dans son utilisation géodésique (Jeudy et al. 1980). Une méthode améliorée de traitement des données a été développée en combinant l'analyse spectrale et l'ajustement par moindres carrés (Jeudy 1980).

Différents projets sont conduits sur les problèmes de nivellement:

- 1) Une analyse des effets de la réfraction sur les mesures de nivellement effectuées à l'Observatoire géophysique de Charlevoix a montré que l'influence de la réfraction est en général très faible dans les conditions spéciales d'observation qui prévalent dans l'application de la méthode qui a été développée (Gagnon et al. 1980a).

- 2) Une étude a été amorcée par J.G. Leclerc en vue de définir plus correctement le problème du nivellement et d'en développer une théorie plus rigoureuse. Des applications seront faites aux nivellements géométrique et trigonométrique dans le champ gravifique terrestre.
- 3) Un programme d'automatisation au niveau de la cueillette des données, des vérifications et des calculs de nivellement a été développé. Ce programme a été mis à l'essai au projet de nivellement spécial de Charlevoix (Gagnon et al. 1980b) et sera étendu aux opérations de nivellement de premier ordre (Jobin 1980).
- 4) Une étude sur l'utilisation de capteurs de précisions pour déterminer les variations d'altitude a été amorcée par J. Jobin.
- 5) Un projet sur l'automatisation des opérations de calibrage des mires d'invar est sur le point d'être complété par J. Jobin.

Dans le domaine de la géodésie astronomique, R. Sanchez conduit un projet sur le développement de méthodes expéditives pour les déterminations de la longitude, de la latitude et de l'azimut astronomiques. Une calculatrice programmable est utilisée pour la mesure du temps, le positionnement du théodolite et le calcul de latitude et longitude à la suite des observations de distances zénithales de deux étoiles appropriées. R. Sanchez a également poursuivi une étude sur le problème du contrôle astronomique de l'azimut géodésique pour les latitudes élevées.

Deux projets sont en cours sur des problèmes reliés à l'application de la méthode de positionnement Doppler:

- 1) Une étude est effectuée par J.C. Usandivaras avec la collaboration de l'Observatoire Royal de Belgique et la Direction de la Physique du Globe (EMR) sur l'analyse de l'influence de certains facteurs sur les résiduelles tels que: la réfraction atmosphérique, le délai du récepteur, la stabilité numérique et les effets systématiques engendrés par les éphémérides précises qui peuvent se traduire par des déplacements des orbites dans l'espace et dans le temps.
- 2) Le développement d'un lien direct pour le transfert des données entre l'équipement Doppler JMR et l'ordinateur IBM via une ligne APL est en voie de réalisation par D. Gélinas.

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

Research continued on problems related to the redefinition of vertical networks in Canada. Many of the general problems associated with the redefinition (Vanicek et al, 1980; Vanicek, 1980b,c), proper definition of orthometric heights (Vanicek, 1980a), datum problems (Castle and Vanicek, 1980) and systematic errors (Vanicek, invited lecture, USGS, Menlo Park, Calif.) were investigated. An intercomparison of gravity prediction techniques was reported in Kassim (1980a,b).

Work supported by the Surveys and Mapping Branch, EMR was continued on the strain of horizontal networks (Thapa and Vanicek, 1980; Thapa, 1980a). A complete software package developed at UNB was successfully implemented on the computer system of the Geodetic Survey of Canada.

Work continued on the utilization of the radar altimetry data collected by the GEOS-3 satellite on Hudson Bay together with Canadian Doppler for the same satellite (Delikaraoglou, 1980). The computation of an altimetry derived sea surface of Hudson Bay was carried out and comparisons to various versions of the geoid were performed in order to establish the degree of usefulness of this technique for the determination of sea surface topography (Delikaraoglou

et al, 1980). Further comparisons including SEASAT altimetry results in Hudson Bay are in preparation.

In cooperation with the Canadian LBI group at York University and with the support of the Earth Physics Branch, EMR work was carried out in the area of Long-baseline Interferometry software improvement (Davidson et al, 1980; Davidson, 1980).

Research continued on sea level variations for the east coast of Canada; especially the zero frequency responses of sea level to atmospheric pressure, temperature and river discharge are being sought.

The Fredericton tiltmetric station is being renovated. New equipment additions include a digital data logger, a multipoint strip chart recorder and an IBM compatible magnetic tape recorder unit. Future plans include replacing the Verlbändert-Melchior horizontal pendulums with Stacey tiltmeters. Analysis of the tilt, pressure, precipitation, etc. data is continuing in an attempt to explain the non-gravitational tilts observed.

Research has been initiated at UNB to study ways in which the NAVSTAR Global Positioning System (GPS) can meet the needs of Canadian Navigation and Geodetic communities. Results of a NAVSTAR performance pre-analysis are reported in Wells and Delikaraoglou (1980).

Work continued on the use of microgeodetic networks in monitoring tectonic movements (Nyland, et al., 1980). Results of four repeated measurements of the Peruvian microgeodetic network (see 1979 Bulletin) have been subjected to various statistical tests within the F.I.G. working group on deformation analysis.

9. York University (Department of Physics)

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

Our efforts in the past have been devoted to LBI validation and comparisons with satellite Doppler measurements. This work revealed a scale bias between the IAU-BIH coordinate frame and the Doppler NSWC 9Z-2 coordinate frame of 0.48 ± 0.05 ppm and a difference in longitude origin of $0^{\circ}87 \pm 0^{\circ}01$.

More recently our work has developed two main thrusts: a) the measurement by LBI of variations in UT1, b) high precision geodetic and astrometric positioning by LBI.

(a) Earth Rotation

The measurement of earth rotation by LBI is being carried out by the group at York along with J.L. Yen of the University of Toronto, J.A. Galt of Dominion Radio Astrophysical Observatory (DRAO), Penticton, B.C., D.N. Fort of Herzberg Institute for Astrophysics, Ottawa, J. Popelar of the Earth Physics Branch of EMR and S. Knowles and W. Waltman of the U.S. Naval Research Laboratory (NRL). This research program uses the 26 m antenna of DRAO, the 46 m antenna of Algonquin Radio Observatory (ARO) and the 26 m antenna of NRL located at Maryland Point, Md. U.S.A. These three antenna are all linked via satellite ground stations and the Anik B communications satellite 12/14 GHz transponder, the use of which is provided to this research effort by the Canadian Department of Communications (DOC), in order that the local oscillator phase may be directly measured on all three baselines and hence be removed as a corrupting noise source degrading LBI UT1 measurements. Results from an experiment performed in April 1980 indicate that the formal errors on UT1 solutions for data obtained on the ARO/DRAO interferometer are ± 300 s and the r.m.s. postfit residual phase delay (including systematics) is as

low as 620 ps. Considerable systematic noise is present in the data, however, some of which can be attributed to unknown phase delay variations in the radio astronomical instrumentation. J.A. Galt of DRAO is constructing phase calibrator systems to be installed in the spring of 1981 on all three antennas. It is hoped that this will remove a major source of systematic noise.

The ARO/DRAO baseline is very nearly east-west and as such the UTL variations deduced from phase delay measured on this baseline are insensitive to errors in the pole position; ± 1 meter error in x and y result in only ± 200 s of UTL error.

Our immediate objectives are to investigate the stability from day to day of the systematic noise in the data, to develop calibration procedures to reduce it, and to produce future high quality UTL measurements. Our use of Anik B has been extended by the DOC on into 1982.

(b) Precision Geodetic and Astrometric Positioning

This research program has as its objective the development of LBI techniques for ultra precise baseline determination for application to crustal dynamics and geodesy. The technique of Low Frequency Phase Synthesis, a variation of Bandwidth Synthesis used by the U.S. groups, is being tested by the group at York along with D.N. Fort of Herzberg Institute for Astrophysics, P. Richards of the Appleton Laboratory of the U.K. and R.B. Langley, formerly of York University currently at M.I.T. In May and June of 1980 transatlantic experiments were conducted involving ARO and Chilbolton Radio Observatory in the U.K. to test this technique. Later in July 1980 a joint experiment using the NASA Mk III LBI system and the Canadian dual channel system was conducted between the Haystack Radio Observatory near Boston, Mass. and the Owens Valley Radio Observatory in California to provide a direct comparison between the Low Frequency Phase Synthesis method and the Mk III wideband group delay method. It is hoped by this technique to provide Canadian geophysicists with a cheaper but competitive LBI system for crustal dynamical studies and geodesy.

10. University of Toronto, (Erindale Campus)/Marshall Macklin Monaghan, Limited

A. Steeves, Lecturer in Survey Science at Erindale College, has completed 5 years (part-time) of research and development for Marshall Macklin Monaghan, Limited, Don Mills, Ontario.

Block Cholesky algorithms were derived for the solution of positive definite symmetric sets of normal equations. Fortran programs were coded for the parametric least squares adjustment of one- and two-dimensional geodetic networks. The GEODOP system of programs (Surveys and Mapping, Energy, Mines and Resources, Ottawa) was rewritten to run on the Burroughs B2700 and the IBM 370 by A. Tarvydas, Marshall Macklin Monaghan Limited; the Block Cholesky algorithms were then used to perform the three-dimensional Doppler adjustment. The photogrammetric block adjustment program written by A. Marin, presently with Energy, Mines and Resources of the Province of Saskatchewan, was recoded and linked to the Block Cholesky algorithms. A seven-parameter photogrammetric block adjustment program is presently being coded by A. Miller, a graduate student at Erindale College and an employee of Marshall Macklin Monaghan Limited.

11. The University of Calgary (Surveying Engineering Division)

Work continues on the design of geodetic networks using interactive computer graphics. The graphics software developed by B.G. Nickerson at the

University of New Brunswick has been implemented at the University of Calgary. The software package has been modified to work on the Princeton 8500M graphics terminal utilizing APL on the Honeywell Multics computer. The software package has proved useful in research as well as in the classroom where it is used in teaching courses in surveying networks. Plans are presently being drawn up that will extend the software package to include planning logistics as well as rewriting of the programme in standard Fortran.

Gravimetric terrain corrections have been investigated by J.A.R. Blais in the context of a feasibility study with the following principal objectives:

- (a) accuracy requirements in western Canada;
- (b) comparative analysis of existing methodologies for computing the terrain corrections;
- (c) optimal utilization of the Earth Physics Branch (EMR) Digital Terrain File for the outer zone contributions; and
- (d) formulation of appropriate digital terrain modelling techniques for the inner zone contributions.

The use of inertial technology in geodesy and surveying constituted one of the major research areas at the Division of Surveying Engineering of the University of Calgary. Three problem areas were singled out: error propagation in inertial positioning, modelling of residual systematic errors after Kalman filtering, and estimation of the gravity anomaly vector from the output of inertial systems. The first problem is discussed in Schwarz (1980b) for the case of optimal Kalman filtering and smoothing. Comparison of the derived results with those obtained from a correlation analysis of actual residuals indicated systematic effects due to sub-optimal filtering or unmodelled hardware errors. Extensive simulations have been carried out to obtain effective methods of pre-mission calibration and post-mission adjustment which will eliminate these errors. Some of the proposed methods are presently tested. Models used to obtain deflections of the vertical and gravity anomalies from the output of inertial measuring units have been studied in Schwarz (1980c). Some shortcomings of the methods presently in use are discussed and a more adequate model is proposed. Comparison of different methods with data taken in a well-controlled testfield are in progress. An evaluation of the state of the art in inertial surveying and a discussion of possible developments is given in Schwarz (1980a).

Studies on the statistical behaviour of gravity anomalies in Canada, started in Schwarz and Lachapelle (1980), have been continued in Lachapelle and Schwarz (1980). Results obtained in a major part of the Western Cordillera are presently used to refine prediction methods for functions of the anomalous potential in mountainous regions.

Research on optimization of surveying and mapping systems has begun with substantial support from Sheltech Canada. The project, coordinated by E.G. Anderson, is initially aimed at defining "the state of the art" of relevant aspects of operations research and decision analysis and testing the applicability of existing techniques to the solution of actual planning and logistics problems in surveying and mapping. Progress has been made in the area of optimizing the scheduling and logistics of observing in geodetic networks and a number of prototype computer programs have been developed. Work is continuing on a proposal to try to link this software to that already employed on a graphics terminal for solutions of the first and second order design problems.

Faculty members in the Division of Surveying Engineering continue to coordinate the establishment of a test and calibration network in the Kananaskis valley 100 km west of Calgary. Its purpose is to serve as a

training as well as a test area. Some 20 points cover an area of about 50 by 25 km. Various observations have been performed in the summer of 1980. They are: directions, distances, astronomic azimuths, astronomic latitudes and longitudes, vertical angles, spirit levelling, gravity differences, and coordinate differences by inertial and Doppler tracking techniques. The data are presently being catalogued and data and results will be made available to potential users sometime in 1981. To date the following groups have made significant contributions to this project: Alberta Department of Transportation, Surveys and Mapping Branch; Sheltech; Federal DEMR, Surveys and Mapping Branch, and Earth Physics Branch.

12. McElhanney Surveying and Engineering, Ltd.

(a) Integrated Navigation

The MSEL Integrated Navigation System, developed and first used operationally in 1979, was employed on two ships during 1980. The system was developed to meet the needs of hydrocarbon exploration activities on Canada's east coast. User response indicates that the system is meeting its design goals. The MSEL system integrates rho-rho or hyperbolic LORAN-C, satellite navigation, ranging or hyperbolic ARGO, Mini-Ranger ranges and ships gyro-compass. Outputs include magnetic tape cassette, video monitor and real-time plotting. Work is continuing to extend and adapt this integrated system to meet changing conditions and user requirements.

(b) Doppler Satellite Positioning

Activities in this domain have centred on three items:

- (i) the streamlining of Doppler Data Processing using the PREDOP/GEODOP series of programs by making them more interactive;
- (ii) the translation of the PREDOP/GEODOP series of programs to IBM compatible format; and
- (iii) the development of Doppler Satellite Network Adjustment software to combine the sub-network of blocks output by GEODOP.

(c) Local Crustal Movements

Three local crustal movement surveys were carried out in 1980. The main ideas of development were:

- (i) the recording on magnetic tape cassette and pre-processing of observations on a micro-computer in the field; and
- (ii) the development and use of the three-dimensional movement analysis software.

13. Sheltech Canada

(a) Field Operations

The application of satellite doppler and inertial positioning techniques was continued (Orr & Hittel 1980). Satellite doppler surveys were carried out in various parts of the world with, for the first time, data processing being carried out in the field using GEOSHELL, a software package using the semi short-arc method (Youngsaye 1979). The monitoring of ice movements in connection with Arctic oil drilling operations utilizing satellite doppler methods (Hittel 1979) was pursued.

The FILS (Ferranti Inertial Land Surveyor) MKII inertial system was used to provide photo control coordinates, second-order control, and coordinates for point gravity densification. Point gravity densification was by far the largest portion of the field work. A fairly accurate elevation (one metre or better) and an approximate horizontal position (fifty metres or better) were required to reduce the ground gravity measures. The best production rate occurred when the gravity measurements and the inertial surveys were done simultaneously.

(b) Research Activities

These were highlighted by the acquisition of a prototype GPS (Global Positioning System) geodetic receiver STI (Stanford Telecommunications Inc.) 5010, a dual frequency, single channel instrument that can track GPS satellites in both range and doppler mode simultaneously. See (Bowie 1979) for a description of the hardware. A computer program (RISET) was prepared to determine the availability of GPS satellites at given time and location and to compute the parameters required to lock-on satellite signals (Bowie and Adams, 1980). The design of real time and post-processing software was also initiated (Adams 1980; Lachapelle, Youngsaye and Beck, 1980). A field experiment to verify the system and study accuracy achievable using various observations and data reduction modes was conducted jointly with U.S. Naval Surface Weapons Center during September.

Research into the use of inertial technology for geodetic positioning has been pursued with emphasis on the FILS MKII system. Problems associated with vertical positioning have been investigated (Hittel & Hagglund, 1980). An investigation of system characteristics and the integration of various external signal sources has been initiated. A study of the relationship between terrestrial and satellite doppler (NWL 9D) systems, carried out in cooperation with the Earth Physics Branch, demonstrated the non-geocentricity ($Z=4m$) of the NWL 9D system and an incompatibility of the order of 0.8 between the zero geodetic meridian plane of this system and the zero astronomical meridian plane of the Bureau International de l'Heure (BIH) (Lachapelle & Kouba, 1980). A comparison of GEOS-3 and SEASAT-A altimetry data with the gravimetric geoid in Hudson Bay, carried out in cooperation with the University of New Brunswick, revealed an agreement better than one metre between the two types of data (Lachapelle & Delikaraoglou, 1980). Research into the statistical behaviour of free air gravity anomalies in the Western Cordillera was carried out in cooperation with the University of Calgary (Lachapelle & Schwarz, 1980).

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I (B) GRAVITY

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1. Introduction

This report has been compiled from information submitted by the principal contributors to gravity and related investigations in Canada. Geodynamics investigations carried out by the Earth Physics Branch are also included in this report.

2. Earth Physics Branch

(a) Gravity Standards

The reobservation of some sixty primary stations and their associated excentres which comprise the first order gravity net in Canada was completed during the past year. Two thirds of the observations were acquired under contract and the remainder by in-house personnel. Preliminary adjustments of the data indicate that the 1980 values are generally within $60 \mu\text{Gal}$ of the 1974 values although a few points show apparent changes of up to $150 \mu\text{Gal}$. Further analysis will be required to determine if these apparent changes are real or can be explained by instrumental or observational errors.

Analysis of results of the 1979 joint Canadian/U.S./Italian experiment to intercompare LaCoste and Romberg gravimeter and absolute measurements over the European calibration line indicate that residual discrepancies of up to $80 \mu\text{Gal}$ exist between the two types of instruments. Subsequent gravimeter observations by the Geodetic Institute of Hannover (Federal Republic of Germany) are now being combined with the original data set to further the investigation of these discrepancies.

Collaborative efforts aimed at extending the Latin American Gravity Standardization Net in Brazil resulted in the successful adjustment of the Sao Paulo state network. This project, carried out in Ottawa by

D. Blitzkow of the University of Sao Paulo will lead to the installation of the Gravity Data Centre's network adjustment software in a computer in Sao Paulo and further joint studies with other Brazilian agencies.

(b) Gravity Data Base

The operation of the National Gravity Data base remains stable and several new features have been added, most notably the implementation of World Data Bank II which permits the superimposition of topographic outlines (coastlines, drainage, etc.) on gravity maps plotted from the data base. The system will be used to create some 80 Open File Maps at a scale of 1:1,000,000 which were hand contoured as part of the compilation process for the 1980 edition of the Gravity Map of Canada. This new edition of the Gravity Map of Canada should be available (in both English and French editions) in the first half of 1981.

(c) Gravity Map Production

One new open file was released during the year. Details concerning the type of map, map scale and location can be found in the bibliography.

(d) Gravity Surveys

Approximately 8350 line kilometres of dynamic gravity data were logged at sea during 1980. In addition 2535 static measurements were made on land and ice-covered coastal areas. Details of the surveys are given in point form below.

(i) British Columbia, Alberta

About 250 new gravity stations were observed in the Rocky Mountains during the final year of a three year contract. Regional gravity coverage at 12 km station spacing (or better) now extends north from the Canada - United States border to latitude 52°N, between longitudes 114°W and 120°W.

Gravity observations at geodetic bench marks were continued during the year. About 1100 measurements were made at precise level bench marks between Edmonton, Alberta and Fort St. John, British Columbia and between Dawson Creek and Prince Rupert, British Columbia. Station spacing along these routes is 1-3 km.

In July and August, 8350 line kilometres of shipborne gravity meter measurements were observed in the area of Queen Charlotte Sound, Hecate Strait, Dixon Entrance and west of the northerly half of the Queen Charlotte Islands to the 200 nautical mile limit.

(ii) Northwest Territories

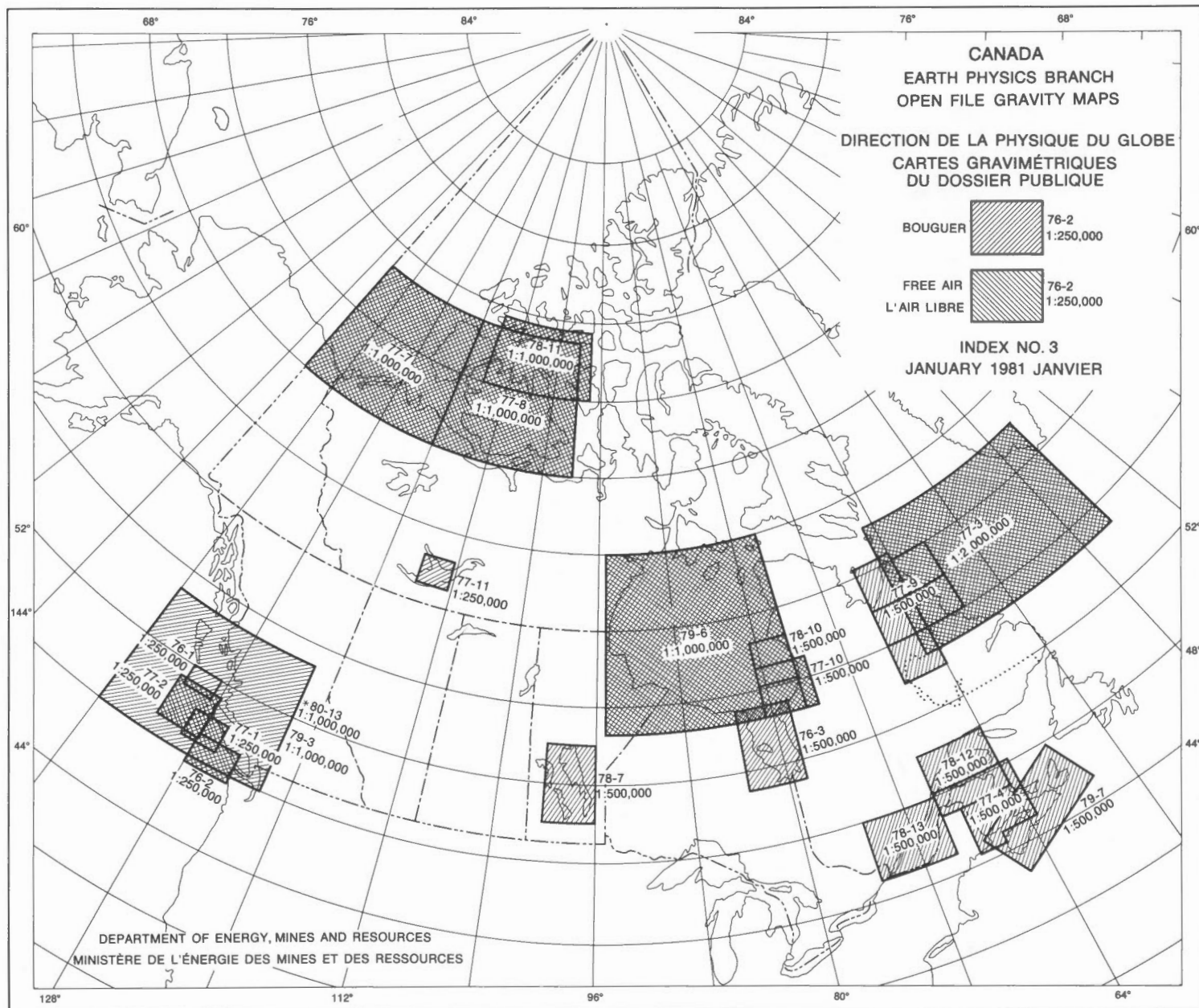
More than 1200 gravity stations at 6 km spacing were established by helicopter traversing on the ice-covered surface of M'Clintock Channel.

(e) Gravity Interpretation and Related Studies

(i) Western Canada

Vancouver Island and S.W. British Columbia

Accumulation and review of tidal, geological and levelling data for Vancouver Island and S.W. British Columbia confirms that the island and a coastal strip of similar dimensions in Washington



* BOUGUER ON LAND — FREE AIR OFFSHORE
* BOUGUER SUR LE CONTINENT — AIR LIBRE AU LARGE

Index Maps Nos. 1 & 2 show no change from January 1980/Les cartes d'index N^{os}. 1 & 2 ne montre pas de changement aux cartes de janvier 1980. See CGB Vol. 32/Voir BCG Vol. 32.

is at present rising (2-4 mm/yr) and that the areas immediately inland are sinking at a similar rate. There seems to be a relation between this process and the continuing subduction of the Juan de Fuca plate beneath the region.

Plate Tectonics

Investigation of magnetic anomalies and other evidence shows that a relative pole of rotation between the Pacific and Juan de Fuca plates can be satisfactorily calculated. Investigation of Juan de Fuca-America motion back to 50 Ma show that the pole has probably always remained in the same quadrant but the motion has progressively declined from 10 to 4 cm/yr.

(ii) Arctic Canada

Lomonosov Ridge

Preliminary analyses of geophysical measurements and sediment samples collected during the Lomonosov Ridge Experiment (LOREX) in 1979 indicate that in the vicinity of the North Pole the Lomonosov Ridge consists of tilted en echelon fault blocks. The combination of ridge morphology, structure, average density, P-wave velocity and sediment character suggests a ridge composed of continental material. Heat flow, aeromagnetic and deep crustal refraction measurements indicate, however, that the continental nature of the Lomonosov Ridge may not be deep-seated in the area of study.

Alpha Ridge

Over the past year a proposal for a major multidisciplinary investigation of the Alpha Ridge in the Arctic Ocean was put forward (Weber et al., 1980) and agreed to in principle. The project is called the Canadian Expedition to Study the Alpha Ridge (CESAR) and its purpose is to advance our understanding of Alpha Ridge structure, composition and age and thereby narrow the choices for its origin. The expedition, planned for the spring of 1983, will include about 40 people and at least 18 geoscience and oceanographic disciplines. Detailed logistical planning and cost analysis are now under way.

Sverdrup Basin

A report is in preparation on the analysis of density data taken from 17 drillholes and gravity and seismic data obtained from two detailed profiles (one along the axis of the basin and the other across the northwestern flank of the basin).

Arctic Archipelago

A report is in preparation on the fragmentation of the Canadian Arctic Archipelago, Greenland and surrounding oceans based on a pattern of northeast trending fractures and northwest trending arches and rifts developed during the last 60 Ma.

(iii) Canadian Shield

Northern Saskatchewan

Detailed gravity data over part of Midwest Lake are being analyzed as part of a larger geophysical, geological and geochemical program carried out in cooperation with the Geological Survey of

Canada and provincial agencies and sponsored by the Nuclear Energy Agency and International Atomic Energy Agency. Preliminary results indicate relatively low gravity anomalies (0.5 mGal) over the radioactive zone.

Monteregian Hills

A program has been initiated to provide gravity coverage of the Monteregian Hills in the Eastern Townships of Quebec. These measurements are part of a geophysical investigation, to be carried out in conjunction with the Department of Geology at Concordia University, to study the subsurface shape and size of these Cretaceous intrusions and their relation to rifting along the Ottawa and St. Lawrence river valleys.

During the summer of 1980, 85 stations were occupied on and around Mont St. Bruno and 71 stations on and around Mont St. Hilaire. In-situ measurements of magnetic susceptibility were also made at selected locations on both hills and, wherever possible, samples were taken for rock-density measurements.

Chalk River

A preliminary Bouguer anomaly map based on observations obtained at 50 m intervals along roads and selected cut lines at the AECL Chalk River site reveals the presence of a distinct, but small amplitude (approximately 1.5 mGal) positive anomaly over the greater part of the area.

Proterozoic Sutures

The literature on proposed Proterozoic sutures in Canada was reviewed and geophysical investigations in the vicinity of three of these proposed sutures were also reviewed. Conclusive evidence for relative motion between parts of the Shield, however, must await more precise paleomagnetic and geochronologic data from critical rocks.

Gravitationally Induced Stresses and Circular Intrusions

There are some examples in North America of enhanced seismic activity at the margins of intrusions. One possible contribution to this seismicity may be gravitationally induced stresses set up due to density differences between the intrusion and the surrounding country rock. Finite-element models have been constructed of low-density and high-density circular disks embedded within much larger disks representing surrounding basement rocks of normal density to study this contribution. It must be emphasized that the magnitude of the stresses involved is only of the order of a few tens of bars so that suitably oriented pre-existing zones of weakness are essential to create any seismic activity as a result of gravitationally induced stresses.

(iv) Free Air Correction

The free air correction is applied to gravity measurements because of the separation between the point of measurement and the reference surface. The correction is applied by using an approximation to the vertical gradient of the particular reference surface used. For many purposes the constant 0.3086 mGal/m is used. This value is not sufficiently accurate however, for today's requirements. Therefore an approximation has been derived, as a function of both latitude and elevation, which is accurate to about $10 \mu\text{Gal}$ at any latitude and up to 6000 m elevation.

(v) Theoretical Gravity

Various approximations have been derived for the calculation of theoretical gravity for a rotational ellipsoid, such as Taylor expansion, power series representation obtained by telescoping, and also by the method of least squares. Comparison of these methods leads to the selection of the best approximation to the gravity formula with greatly increased speed and simplicity.

(vi) Constants for a Reference Surface

If a reference ellipsoid is changed by redefining the basic four parameters (a , GM , J_2 and ω), then all other constants used in gravity and geodesy such as γ_e , γ_p , γ , a , b , e^2 , etc. must be calculated. Some computations have been carried out primarily to calculate these new constants for the GRS1980 and also to select the most appropriate computational forms (in many cases there are alternative formulations to calculate one constant).

(f) Dynamic Gravimetry

(i) Straight-Line Gravimeter Test

A new LaCoste and Romberg straight line marine gravimeter (SL-1) was tested by comparison with two S-meters (S-56 and S-41) aboard CSS PARIZEAU off the British Columbia coast. The new meter is unique because its design eliminates inherent cross-coupling errors.

(ii) S-Meter Reconfiguration

A microprocessor-based controller is being developed for the S-meter and inertial platform. It will replace the analog controller circuits and provide real-time data logging and processing. The prototype is complete, final construction has commenced and testing is planned for the 1981 field season.

(g) Geodynamics

(i) Precise Gravimetry

Relative calibration curves have been calculated for four model D gravimeters using ten thousand observations obtained over a five year period. Adjustments of data for individual surveys in local networks show good agreement among instruments. The ~~16~~ errors on station values in two-instrument surveys average 2-3 μ Gal.

Semi-annual resurveys of precise gravity networks in seismically active areas of Charlevoix, Quebec and Vancouver Island, B.C. continued through 1980. Using the mean network gravity as a datum a comparison of observed temporal variations ($\sim 10 \mu$ Gal) at Charlevoix with estimates of moisture input from rainfall and snowmelt shows a significant correlation at some stations. A tentative explanation in terms of crustal deformation has been proposed.

(ii) Measurement of Crustal Tilt and Strain

Monitoring of tilt, strain and water levels was reduced to the operation of a single observatory at Charlevoix, Quebec during 1980. As reported in previous years no variations that could not be explained by direct meteorological, groundwater or co-seismic effects were observed in 1980. However, significant (10-15%)

changes in tidal tilt amplitude over the last four years are still under investigation. The present experiment will study the spatial coherence of observed tilt as measured by near-surface, short-baselength tiltmeters (Earth Physics Branch) precise releveling of a local bench mark array (Universite Laval), and vertical pendulum borehole tiltmeters at 50 m depth (Dalhousie University). It is hoped that a practical method of observing tectonic tilt will emerge from this experiment.

Preliminary tilt observations at the Pacific Geoscience Centre, Sidney, B.C. show an extremely large tidal load tilt of the order of 1μ radian peak-to-peak, a response to heavy precipitation of the order of 5μ radians and permanent offsets due to local blasting. The apparent lack of stability of this site has resulted in the cancellation of work on the installation of a hydrostatic tiltmeter.

(iii) Aquifer-Tide Studies

Tidal and atmospheric pressure induced variations in water levels have been monitored since 1978 in seven uncased boreholes at Chalk River, Ontario. It has been shown theoretically and demonstrated experimentally using the Chalk River data that the water level variations are diagnostic of dip, strike and aperture of the dominant fracture intersecting the borehole. Tests in cooperation with the University of Waterloo have also proven the feasibility of pressure measurements within a packed-off section of a borehole. This technique should enable specific fractures to be examined in detail.

3. Atlantic Geoscience Centre

(a) Marine Gravity Measurements

Some 2,820 line kilometres of gravity data were collected on the continental shelf off northeastern Baffin Island and in parts of Davis Strait. These measurements were generally of a reconnaissance nature, and were carried out aboard CSS HUDSON in conjunction with a seismic reflection and bedrock sampling program.

In a multiparameter survey program carried out in cooperation with the Canadian Scientific Ships BAFFIN and HUDSON, a total of 10,844 line kilometres of gravity data were collected in Davis Strait and on the Labrador shelf. In Davis Strait, coverage consisted principally of east-west lines 38 km apart extending from Baffin island to Greenland. On the Labrador shelf, gravity data were collected over Nain, Makkovik, and Harrison Banks, with lines 38 km apart roughly at right angles to the coast and extending out to the 500 m contour.

Graf-Askania Model Gss-2 Sea Gravity Meters were used for all measurements.

(b) Labrador Sea Gravity Data

Serious problems have been encountered in merging gravity data from various cruises in the Labrador Sea. An analysis of discrepancies at track crossover points has revealed important errors which need to be corrected. Accordingly, various portions of the data are being reprocessed, and the entire set will be subjected to an adjustment procedure designed in cooperation with the Gravity and Geodynamics Division, Earth Physics Branch to achieve high internal consistency. This work should be completed in 1981, at which time the data will be released to Open File and will be submitted for publication at a scale of

1:250,000 in the Natural Resource Map Series. (A preliminary compilation at a scale of 1:2,000,000 was released in 1979 as GSC Open File No. 627.)

(c) Scotian Margin

Gravity data collected over some 14,000 line kilometres on the Scotian shelf during a multiparameter survey in late 1979 has been prepared for release to Open File by early 1981. The collection and processing of these data was a project carried out in cooperation with the Canadian Hydrographic Service and the Gravity and Geodynamics Division of the Earth Physics Branch.

(d) Appalachian Gravity

A compilation of gravity data for the Appalachians compatible with Williams' Tectonic-Lithofacies map at a scale of 1:1,000,000 is now in press and should appear by late 1980. An overall description of the gravity field of the Appalachians and its correlation with the geology and magnetic field have been prepared for publication in the proceedings of the North Atlantic Borderlands Symposium held in St. John's in 1979. The significance of the gravity gradient interpreted as being coincident with the eastern edge of Grenville basement has been enhanced with publication of the results of the COCORP deep seismic reflection program in the southern Appalachians.

Compilation of gravity data over Caledonide areas in Europe is now proceeding with the prospect of correlating features of the gravity field with deep structural features observed seismically there and comparing that correlation with correlations found in the Appalachians.

(e) Gravity Modelling

In cooperation with Dalhousie University, the nature of gravity anomalies predicted by geodynamic models for the evolution of rifted continental margins has been investigated, and compared with observational data. The models describe the subsidence and thermal history of the margins after stretching and thinning of the lithosphere during initial continental rifting. The rheology of the lithosphere is assumed to be a function of temperature and is modelled by an elastic plate whose thickness varies with time and with lateral position across the margin, according to the depth of a specified isotherm.

(f) Instrumentation - New Gravimeter

In a move to upgrade its inventory of aging instruments, AGC has ordered an Askania Model Kss-30 Sea Gravity Meter. The Kss-30 features high accuracy, compact design, longterm stability, cross-coupling free operation, and an integral microprocessor for the real-time computation of the Eotvos correction and the free-air gravity anomaly. Delivery is slated for June, 1981.

In preparation for this acquisition, preliminary design work is underway for a computer-based data logger/interface unit, which will supply updated position coordinates from BIONAV (Bedford Institute of Oceanography Integrated Navigation System) to the Kss-30 and which will log gravity output for subsequent processing and archiving.

4. Memorial University of Newfoundland

During 1980 gravity mapping recommenced in Newfoundland. The present activity consists of mapping at 2.5 km spacing on roads of the Avalon Peninsula. A total of 196 gravity stations was occupied during 1980 and two new sub-bases were established. All elevations were determined by barometric

levelling and the data will be placed on file at the Earth Physics Branch, Ottawa.

Work has also been re-initiated on examining gravity data inversion schemes for determining subsurface mass distributions.

5. Nova Scotia Department of Mines and Energy

The geophysical edition of the new Geological Map of the Province of Nova Scotia, 1979, includes an overlay of the Bouguer gravity anomaly data compiled by the Gravity and Geodynamics Division, Earth Physics Branch, Department of Energy, Mines and Resources, Ottawa, from information in the National Gravity Data Base current to June, 1978. The gravity data provide valuable insights into the deep structure of the South Mountain Batholith and the Carboniferous Basins with their associated salt domes. Copies of the map are available from the Nova Scotia Department of Mines and Energy, P.O. Box 1087, Halifax B3J 2X1.

6. Nova Scotia Research Foundation Corporation

A gravity survey, including data reduction and interpretation, was carried out for a mineral exploration company in Newfoundland. Gravity data in the Bras D'Or Lake area of Cape Breton Island was sold to companies exploring for potash. Gravity data compilations and interpretations were carried out for various mineral exploration companies working in the Atlantic Provinces and Saskatchewan.

Estimation of terrain corrections continues for gravity stations in southeast Cape Breton Island. Corrections vary between a few tenths of a milligal to more than one milligal. A hand calculator program has been written to reduce gravity data in the field. The program corrects stations measured on land or on frozen lakes and can apply the 1930 or 1967 International Gravity Formula.

7. Laval University

Geophysical methods have been used to study ophiolite complexes of the Quebec Appalachians in the Eastern Township - Gaspé area. Iterative modelling of the magnetic and gravimetric fields with a graphical system using a cathodic ray screen display has shown that ophiolite slabs of varying thickness dip steeply to the southeast or to the south. These transported slabs are imbricated in wedges of country rocks (metasediments piled up like an onion skin structure - thin skin tectonics). From this model, an insight on the mode of emplacement of the ophiolitic blocks has been deduced.

8. Ontario Geological Survey, Ministry of Natural Resources

Field work carried out in the summer of 1980 completed the third and final year of the Gravity Field Surveying Program within the Cobalt Embayment and the Grenville Front. The two earlier surveys were in the North Bay-Cobalt-Englehart and Elk Lake areas and the Gowganda, Shining Tree and Gogama areas. An interpretation program combining the survey data from three summers' work, 7,000 gravity stations in a 33,000 km² area, will soon be undertaken by the staff of the Geophysics/Geochemistry Section.

9. University of Toronto

Investigations were carried out numerically on the adequacy of interpretation schemes for gravity, based upon Backus-Gilbert inverse theory. Studies with synthetic bodies led to an improvement in the method, chiefly in the selection of the sizes of prisms to represent the body, and in the application of weighting factors to enhance the solutions. Applications to real cases were made over scales ranging from ore bodies to crustal features. In particular, new interpretations were made of the well-known Cyprus positive

anomaly, and of the negative anomaly which parallels the Grenville Front in west-central Quebec.

10. University of Calgary

(i) Devonian Reef Study

Detailed gravity measurements over several Devonian reef complexes in central Alberta were made with the aim of determining whether density variations due to dolomitization of sediments above and around the reef structures is evident from measured gravity anomalies. Relative Bouguer anomalies of up to 0.2 mGal are observed over the reefs and initial interpretations indicate that dolomitization outside of the reefs is significant. Two and three-dimensional modelling will continue into 1981 and the study will be completed by mid-year.

(ii) Claresholm Study

This project involves making gravity measurements along a 60 km seismic line in southern Alberta. The seismic data show small but well-defined block faulted structures in the Precambrian basement. The aim of this study is to determine whether the gravity method can be used to assist seismic interpretation of the basement fault structures, particularly in the foothills belt.

(iii) Norman Range Study

A gravity survey over the Norman Range, north-east of Norman Wells, Northwest Territories was undertaken for the Institute of Sedimentary and Petroleum Geology. The objective of this study is to determine whether tectonic thickening of the Saline River Formation (dominantly salt) occurs in the core of the Norman Range, hence allowing the depth to the thrust decollement to be determined. The data at present are being interpreted and the report will be available at year end.

11. University of Windsor - Department of Geology

A small field survey has been completed and published to demonstrate the practical use of gravity survey methods to locate Paleozoic pinnacle reefs in south-western Ontario.

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II SEISMOLOGY AND PHYSICS OF THE EARTH'S INTERIOR

Compiled by: E.R. Kanasewich

1. Canadian Seismograph Stations
2. Canadian Seismicity - Earth Physics Branch, Ottawa, and Pacific Geoscience Centre, Sidney, B.C.
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6. University of Alberta
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9. University of Saskatchewan
10. University of Toronto
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12. Bibliography
1. Canadian Seismograph Stations

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

The following changes were made to the Eastern and Western Canadian Telemetered Networks (ECTN and WCTN). On February 7, 1980, a new computer operating system was installed for the WCTN at the Pacific Geoscience Centre to facilitate network expansion. On June 20, 1980, the new radio-telemetered station HNB at Haney, B.C., commenced operation via a relay station on Saturna Island, replacing the former telephone-linked station HYC. Station LPQ at La Pocatière, Québec, and station SBQ at Sherbrooke, Québec, were added to the ECTN on June 6, 1980 and August 12, 1980, respectively. Following installation of a front-end micro-processor to handle incoming data lines for

the ECTN on December 9, 1980, two additional stations, VDQ at Val D'Or, Québec and WBO at Williamsburg, Ontario, were added to the network.

All standard and some regional seismograms are microfilmed in Ottawa by the Canadian Government Public Archives, and copies of the 35 mm microfilm are deposited with the U.S. Department of Commerce, NOAA, EDS Solid Earth Data Division in Boulder, Colorado 80302, which answers international requests for Canadian Seismograms. The annual publication 'Canadian Seismograph Operations' summarizes information on those seismograph installations operated by or for the Division of Seismology and Geothermal Studies, Earth Physics Branch. This report also gives the characteristics of the various systems and describes the format and availability of the recorded data.

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

(a) Canadian Earthquakes

(i) Preliminary Summaries, Catalogues and Earthquakes of 1980

The EPB prepares and distributes to interested organizations preliminary bi-monthly summaries of all Canadian earthquakes approximately 7 months in arrears. The purpose of the lists is to provide interested organizations with a complete (but not final) picture of Canadian data on all Canadian earthquakes to be included in the International Seismological Centre's world-wide bulletins. Those organizations interested in receiving such bi-monthly summaries of Canadian earthquakes should contact the Division of Seismology and Geothermal Studies, Earth Physics Branch, Department of Energy, Mines and Resources, Ottawa, K1A 0Y3.

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

(ii) Special Studies

Eastern Canada

The magnitude 5.3, Sharpsburg, Kentucky, earthquake of 27 July 1980 was felt by many persons and created much Canadian media interest in earthquakes. Data from Canadian stations were employed by A.E. Stevens (EPB) to calculate an m_b of 4.9 and m_b (Lg) of 5.5. The magnitude of 5.3 is considered the best estimate based on Canadian data.

Small earthquakes with magnitudes less than 2.5 were felt in Burlington, Ontario on February 28, March 14 and September 28, 1980. Nearby monitoring by an EPB seismograph over the period from December 1979 through April, 1980, has shown that the source of the activity is confined to a small area under Burlington at a depth of less than 2 km, and may be related to post-glacial deformational features that occur in that region.

Seismic monitoring of the LG-2 reservoir, Québec, continued via the telemetered station LDQ. Only a few microearthquakes were recorded but not located. The regional station LGQ stopped operating at LG-2, and a new regional station LTQ was established at the LG-3 dam site in May 1980 (Table 1).

Table 1 Canadian Seismograph Stations (December 31, 1980)

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.	INK	Inuvik, N.W.T.	68.29 133.50	
7.	LHC	Thunder Bay, Ont.	48.42 89.27	
8.	MBC	Mould Bay, N.W.T.	76.24 119.36	
9.	MNT	Montréal, P.Q.	45.50 73.62	
10.	OTT	Ottawa, Ont.	45.39 75.72	
11.	PGC	Sydney, B.C.	48.65 123.45	
12.	PHC	Port Hardy, B.C.	50.71 127.43	
13.	PNT	Penticton, B.C.	49.32 119.62	
14.	RES	Resolute, N.W.T.	74.69 94.90	
15.	SCH	Schefferville, P.Q.	54.82 66.78	
16.	SES	Suffield, Alta.	50.40 111.04	
17.	STJ	St. John's, Nfld.	47.57 52.73	
18.	YKC	Yellowknife, N.W.T.	62.48 114.47	
Regional Stations (Energy, Mines and Resources)				
19.	BLC	Baker Lake, N.W.T.	64.32 96.02	
20.	BMS	Minton, Sask.	49.21 104.79	
21.	CHQ	Charlesbourg, P.Q.	46.89 71.30	
22.	DLY	Dezadeash Lake, Y.T.	60.37 137.06	
23.	EFO	Effingham, Ont.	43.09 79.31	
24.	FSB	Fort St. James, B.C.	54.48 124.33	
25.	GDR	Gold River, B.C.	49.78 126.05	
26.	HAL	Halifax, N.S.	44.63 63.60	
27.	IGL	Igloolik, N.W.T.	69.38 81.81	
28.	KEY	Kluane Lake, Y.T.	61.05 138.50	
29.	SIY	Silver City, Y.T.	61.03 138.41	Closed March 27, 1980
30.	KRY	Koidern River, Y.T.	61.97 140.41	
31.	LGQ	La Grande, P.Q.	53.69 77.73	Closed May 17, 1980
32.	LTQ	La Grande, P.Q.	53.70 76.09	Commenced May 17, 1980
33.	LMQ	La Malbaie, P.Q.	47.55 70.33	
34.	MCE	Mica Creek, B.C.	52.01 118.56	
35.	PBQ	Poste-de-la-Baleine, P.Q.	55.28 77.74	
36.	POQ	La Pocatière, P.Q.	47.36 70.04	Closed October 17, 1980
37.	PWM	Pinawa, Man.	50.19 96.04	
38.	QCQ	Québec City, P.Q.	46.78 71.28	
39.	SIC	Sept-Iles, P.Q.	50.19 66.74	
40.	SKB	Skidegate, B.C.	53.25 132.00	
41.	SUD	Sudbury, Ont.	46.47 80.97	
42.	UNB	Fredericton, N.B.	45.95 66.63	
43.	WHC	Whitehorse, Yukon	60.74 135.10	

Table 1 (continued)

STATION CODE	STATION	LATITUDE N	LONGITUDE W	COMMENT	
Eastern Canadian Telemetered Network (ECTN) (Digital recording, Single Component) (Energy, Mines and Resources)					
44.	FHO	Fitzroy Harbour, Ont.	45.45	76.22	
45.	GAC	Glen Almond, P.Q.	45.70	75.47	6 channel borehole seismograph
46.	GNT	Gentilly, P.Q.	46.36	72.37	
47.	LDQ	La Grande, P.Q.	53.54	76.97	
48.	LPQ	La Pocatière, P.Q.	47.34	70.01	Commenced June 6, 1980
49.	MIQ	Maniwaki, P.Q.	46.37	75.97	
50.	MNQ	Manicougan, P.Q.	50.53	68.78	
51.	MNT	Montréal, P.Q.	45.50	73.62	
52.	OTT	Ottawa, Ont.	45.39	75.72	
53.	SBQ	Sherbrooke, P.Q.	45.38	71.93	Commenced Aug. 12, 1980
54.	VDQ	Val D'or, P.Q.	48.23	77.97	Commenced Dec. 9, 1980
55.	WBO	Williamsburg, Ont.	45.00	75.28	Commenced Dec. 9, 1980
Western Canadian Telemetered Network (WCTN) (Digital Recording, Single Component) (Energy, Mines and Resources)					
56.	ALB	Port Alberni, B.C.	49.27	124.83	
57.	HYC	Haney, B.C.	49.26	122.57	Closed July 4, 1980
58.	HNB	Haney, B.C.	49.27	122.58	Commenced June 20, 1980
59.	PGC	Sydney, B.C.	48.65	123.45	
60.	PIB	Pender Island, B.C.	48.80	123.32	
Yellowknife Array, N.W.T. 18 elements of short-period vertical recording (Analog Telemetry) 3 elements of long-period vertical recording					
61.	YKA	Yellowknife Array	62.493	114.605	Centre
Special Stations					
62.	Charlevoix Array, La Pocatière, P.Q.		47.55	70.33	A seven-element telemetered array recording on analog tape. Commenced operation Aug. 30, 1977.

Table 1 (Continued)

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

D.A. Forsyth and R.J. Wetmiller (EPB) completed a review of seismicity and other geophysical data in the area of Nares Strait. The results show that Nares Strait is essentially aseismic and displays none of the seismic characteristics of a major rift zone.

H.S. Hasegawa and R.J. Wetmiller (EPB) have completed a detailed analysis of the M_b (Lg) 5.0 Charlevoix earthquake of August 19, 1979. Aftershock activity indicated a focal depth of 10 km and fault dimensions of a few kilometres for the main shock.

Central Canada

D.J. Gendzwill (University of Saskatchewan), R.B. Horner and H.S. Hasegawa (EPB) have correlated four minor earthquakes ranging in magnitude from 2.3 to 3.0, that occurred between November, 1979, and August, 1980, with a potash mining operation near Saskatoon. Previous seismicity in the region was unknown.

Western Canada

R.J. Wetmiller (EPB) conducted a field survey of earthquake activity in the area west of Rocky Mountain House, Alberta, in September and October. Six EPB and one University of Alberta seismographs were deployed. One hundred and thirty-five earthquakes were recorded, 59 on three or more stations and 14 in digital format. All the activity appears to be concentrated near the gas wells of the Strachan Gas Plant operated by Gulf Resources Canada Ltd.

R.B. Horner and J.A. Drysdale (EPB) are continuing their analysis of low-level seismicity in the southwestern Yukon Territory, in a joint venture with Foothills Pipe Lines Ltd., that will end on March 31, 1981. An analysis of seismicity before and after the 1979, magnitude 7.2, St. Elias earthquake, as a basis for understanding the complicated plate interaction in the eastern Gulf of Alaska region, was completed by C.D. Stephens, J.C. Lahr, K.A. Fogleman (U.S. Geological Survey) and R.B. Horner (EPB).

On March 7, 1980, there was a $M_L = 4.8$ earthquake on the west coast of central Vancouver Island. G.C. Rogers (PGC) has calculated a preliminary focal mechanism that suggests a high angle thrust event.

(b) Strong Motion, Seismic Risk and Earthquake Engineering

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

In the research project on seismic risk maps for Canada, preliminary versions of probabilistic peak acceleration and peak velocity maps have been prepared for western and eastern Canada at risk levels of 0.01 per year and 10 percent in 50 years.

As part of the geophysical activities within the EMR/AECL program on disposal of radioactive waste, EPB staff are undertaking seismotectonic compilations of various regions of Ontario and western Québec to aid long term assessment of earthquake risk. During 1980 work has concentrated on a map sheet centred on the 1935

Temiskaming earthquake. Geological, geophysical and Landsat compilations are being made to assess the seismotectonic characteristics of a region of moderate seismicity, which will be extended to other areas to provide a "geologic" estimate of earthquake potential over long time intervals.

D.A. Forsyth (EPB) is supervising contracts for Landsat lineament studies for two areas in northwestern Ontario as part of the Branch effort to provide advice to AECB, provincial power authorities and other agencies on seismic risk assessment.

D.H. Weichert and W.G. Milne (PGC) have completed an assessment of the existing Canadian strong motion records and processing methods. They conclude that the older standard programs have produced spurious long-period velocities and displacements. The number of requests for site specific seismic risk estimates coming from the engineering and consulting community continues to grow.

3. Atlantic Geoscience Centre

I Seismology

(a) Seismic Refraction Studies

The AGC Ocean Bottom Seismometers (BOBS) have been used in various oceanic and continental shelf regions. They have also undergone continuous modification and improvement within the last year. Some of the activities are outlined below.

LADLE (Lesser Antilles Deep Lithosphere Experiment)

This project was designed to study the velocity structure of the upper mantle, down to depths of 100 km. A 1000 km long array of ocean bottom seismometers (OBS) was deployed, at a spacing of 60 km, and recorded large explosive shots (2 to 5 tons) and earthquakes from the Lesser Antilles region. The array was situated on 100 Ma old North Atlantic oceanic crust, along a north-south line, southeast of Bermuda and north of the Lesser Antilles. The experiment was a joint undertaking of the Institute of Oceanographic Sciences, U.K., Institut de Physique du Globe, France, the University of the West Indies, and the Atlantic Geoscience Centre. C. Keen, B. Loncarevic, D. Heffler and D. Barrett were the main Canadian participants using the CSS DAWSON for OBS work and for shooting.

Preliminary results suggest that a slow increase of velocity with depth best fits the data, to ranges of 700 km. High P-wave velocities of 8.5-8.6 km/s are observed at depths of about 50 km. This model is simpler, but better constrained, than many derived from earlier studies of the same type.

VISP (see also UBC and PGC reports)

Four Ocean Bottom Seismometers (BOBS) were used in August 1980 as a part of the instrumental array during VISP-80 (Vancouver Island Seismic Project) by B. Loncarevic. Two BOBS were launched on the Continental Shelf west of Vancouver Island to complete a 60 km long refraction line using a 2000 cu in air gun. Two BOBS plus one OBS from PGC (R.D. Hyndman) were used in deep ocean for a long refraction line (120 km) paralleling the continental slope.

FRAM

The Atlantic Geoscience Centre has continued its participation in the Fram series of drifting ice stations (1979, 80, 81) in the Eurasian Basin. R. Jackson (AGC) along with I. Reid from Dalhousie in 1979 and A. Baggeroer from MIT in 1980 have been working jointly in the investigation of the crustal structure of this region. The work has been carried out using the AGC ocean bottom seismometer, seismic reflection equipment, a gravity corer, MIT's hydrophone array, and in 1981 a heat flow probe will be added. The regional picture of the area is characterized by the slow spreading, 5mm/yr, Arctic Mid Ocean Ridge. The magnetic amplitudes are low except in areas affected by the Yermak hot spots. Crustal thickness measurements indicated thin crust in regions of low magnetic amplitudes.

(b) Intercalibration of OBS and Instrument Design

In many large seismic refraction experiments several types of instrument are pooled together. To enhance subsequent interpretation, it is important to know the relative response characteristics of different instruments. AGC has participated in two such international intercomparisons: Lopez Island Experiment in 1978 and CALOBS Experiment in Brest, France in May 1980 (B. Loncarevic, D. Heffler). In the latter experiment, instruments from Japan, France, Germany and U.K. were available for intercomparison. Tests were carried out in a deep tank facility under controlled conditions which could be reproduced from test to test.

The signals received by BOBS are recorded on a slow moving magnetic tape using a Direct Analog method. The recording time is extended by a factor of 120 to 200 by slowing down the tape transport. At these slow speeds, the response of the magnetic recording medium is pushed well beyond the design specifications. A careful choice has to be made regarding the tape type and the recorder bias setting in order to ensure the optimum performance. Twelve tapes by different manufacturers were evaluated by B. Loncarevic for use in BOBS recorders.

II Physics of the Earth's Interior

Modelling of the evolution of rifted continental margins is being carried out by C. Keen, in cooperation with C. Beaumont (Dalhousie University). Numerical models are produced, based on assumptions concerning the mechanisms responsible for rifting, the rheology of the lithosphere, and the sediment supply. Gravity anomalies, crustal structure, basin stratigraphy and paleotemperatures are predicted by the models, and compared with observed geological and geophysical data.

4. 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 during 1980 by G. Buchbinder in the La Malbaie region, Québec, and recorded by EPB staff using up to 17 instruments at up to 14 sites. In June, two shots were set off, one on the north shore and one on the south shore. This was repeated in October. The June and October shots were respectively up to 30 ms and 40 ms earlier than the 1979 shots.

A.G. Green has completed the interpretation of the multi-coverage seismic reflection survey across the faulted contact of the Thompson nickel belt with the Churchill province in northern Manitoba. The crust

beneath the Thompson nickel belt has a number of prominent horizontal or north west dipping reflectors, which are truncated at the faulted contact with the Churchill province.

A.G. Green, in collaboration with geophysicists at the Universities of Manitoba, Saskatchewan and Western Ontario is continuing with the interpretation of the 1977 and 1979 COCRUST seismic surveys across the Superior-Churchill boundary zone in southern Canada. A.G. Green and Z. Hajnal (University of Saskatchewan) have interpreted the reflection data collected across the boundary zone. Three distinct zones of reflection character have been delineated, which correspond to the previously defined geologic/tectonic zones in this region. A variety of techniques, including ray tracing and synthetic seismogram analysis, are being applied to the five lines of refraction data.

J.A. Mair and J.A. Lyons have completed a study of crustal structure and velocity anisotropy beneath the Beaufort Sea. Refraction data obtained during the AIDJEX experiment in 1976 reveal a 4 to 5 km thick sedimentary layer overlying an oceanic crust that thickens rapidly as it approaches the continental terrace of Alaska. The direction of maximum upper mantle velocity appears to be approximately north-south in the area surveyed, suggesting that a rotation of the Northwind Ridge/Chukchi Plateau away from the Barrow/Martin Point sector of Alaska may have occurred.

D.A. Forsyth, J.A. Mair and A.G. Green completed a preliminary interpretation of the data from shotpoints 4, 5 and 6 of the refraction profile across the Red Sea - Arabian Shield transition.

J.A. Mair, D.A. Forsyth, A.G. Green and R. Grogan participated in a refraction-reflection survey across the length and breadth of Vancouver Island during August, 1980. This project was a continuation of the cooperative efforts between Canadian universities and EPB (COCRUST) to obtain large-scale refraction data and multi-fold reflection data in areas of tectonic or economic interest. A.G. Green and D.A. Forsyth have completed preliminary reduction of the EPB data. The data are being interpreted at the University of British Columbia before they are released to other interested groups.

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

In October 1979, a seismic source consisting of a 700 kg weight that could be dropped vertically or made to slide down a ramp inclined at 45° to the vertical was tested by EPB staff as a source of P, SV and SH waves at a site near Chalk River, Ontario. The seismic energy was recorded by arrays of both horizontal - and vertical - component geophones at distances between 30m and 600m from the source, which was operated over a gneiss-monzonite rock body overlain by glacial overburden varying in thickness from less than a metre to a few tens of metres.

C. Wright and P. Johnson found that the seismic energy was more efficiently generated when the overburden thicknesses were at least several metres. The signals identified visually as S are generally true S, although some may be the converted wave (P)S.

C. Wright and D. Hoy used the pulse rise-time method of Gladwin and Stacey to study broadening of the P-wave arrivals on the seismograms produced by the weight drop source. One of two data sets showed a significant increase in pulse rise-time, τ , as a function of travel

time T. This increase, if due to anelastic attenuation in the uppermost part of the rock body, implies a Q value of 243 ± 53 , assuming a linear relationship between τ and T.

C. Wright and C. Huang (Geological Survey of Canada, GSC, and AECL) have devised a method of calculating P-wave velocity-depth profiles from crystal cable well surveys that makes maximum use of the data redundancy. The method has been tested using a set of 2000 seismograms recorded by GSC personnel at depths between 20 and 260 m in a borehole at Chalk River. These seismograms were generated by 183 small shots detonated in shot holes located on the surface a few metres from the top of the borehole. The best velocity-depth curve in the gneiss-monzonite rock body shows minima that correlate well with the positions of major fractures or high concentrations of fractures inferred from optical examination of core samples, laboratory measurements of seismic velocities and tube wave studies.

J.A. Mair and A.G. Green have obtained and interpreted high resolution seismic surveys (Mini-Sosie) over the Lac du Bonnet batholith near Pinawa, Manitoba. A steeply dipping system of fractures pervades the batholith to depths of 1 km or greater and a major low-angle thrust fault is clearly indicated at depths of several hundred metres.

A seismological experiment over a granite pluton was completed by contract to industry at Pinawa, Manitoba, in September, 1980. Both the shear-wave hammer tested at Chalk River and conventional explosives were used as sources, and the seismic energy was recorded on the surface, using both vertical- and horizontal- component sensors at distances up to 540 m, and in two boreholes using three-component lock-in geophones. The purpose of this experiment was to obtain detailed P- and S-wave velocity and amplitude variations and to relate them to fractures or fracture systems within the rock body.

(b) Seismological Instrumentation

The Eastern Canada Telemetered Network (ECTN) has been considerably expanded during 1980. New seismic stations have been installed at Williamsberg (Ontario), La Pocatière (Québec), Val D'Or (Québec) and Sherbrooke (Québec). An additional station at Chalk River (Ontario) will be operating early in 1981, and installations for another station at Mont Tremblant (Québec) are almost complete.

To facilitate transmission of data from several of these sites, radio-repeaters were established at Foymount, Ontario, and Camp Fortune, Québec, with a third repeater planned for Mont St. Marie, Québec.

It became evident a year ago that the existing data processing facility at Ottawa would be severely taxed with the proposed expansion of the ECTN. To ease the demands on the PDP11/34 processor, an LSI-11/23 was added as a pre-processor for the system. A new version of the ECTN software has been developed to share the data processing load between the two computers. Much of the communications protocol, and preliminary formatting of the data is now handled by the LSI processor, leaving the trigger algorithms and data storage tasks to the PDP 11/34.

Much effort has gone into developing suitable data-concentration schemes to make better use of the bandwidths available in both the standard voice-grade telecommunication lines and our UHF radio equipment. Coding schemes to identify data packets, and techniques for minimizing the timing uncertainties have been studied. Thus far, primitive versions of concentrator software have been developed to amalgamate two 1200 baud data streams into one 2400 baud stream. Refining and expanding of these programs is continuing.

During the past year, sites for three new stations to be added to the Western Canada Telemetered Network (WCTN) were prepared at Campbell River, Sechelt, and Saturna. The existing station at Haney was upgraded using modern hardware, and data transmission is now via UHF radio. The new station at Saturna will serve as a concentration point for the data streams received from the other three stations. Further information on WCTN is given in section 5I(b).

Three field programs made use of the 'Mk 2 Backpack' recorders. Eight units were deployed in the La Malbaie area of Québec in June. Twelve were used in the COCRUST II co-operative experiment on the west coast in August. During this deployment one unit was damaged beyond repair, presumably by vandals. The remaining eleven were again used at La Malbaie in October.

Two items of hardware were developed during the year; a transmit-only modem for use with the uni-directional data streams on the ECTN/WCTN systems, and a battery evaluator and maintainer for use with the 'Backpak' recorders.

Staff in the instrument section include R. Hayman, F. Kollar, F. Anderson, J. Lyons and J. Thomas. F. Lombardo retired during 1980 after more than thirty years service with the Earth Physics Branch.

II Physics of the Earth's Interior

(a) Heat Flow and Heat Production

Temperature data from oil well records in the Prairie Provinces have been collected and analysed by J. Majorowicz. He has shown a wide range of heat flow, from 51 mW/m² to 99 mW/m² in the western part of the western platform. The average value of 73 mW/m² is well above the world average for Precambrian platforms.

A regional analysis of heat flow on the Island of Newfoundland has been completed. This was a cooperative project between J.A. Wright of Memorial University and A.M. Jessop, A.S. Judge, and T.J. Lewis of the Earth Physics Branch. The ten heat flow values averaged 50 ± 4 mWm⁻² ranging from 38 to 82 mWm⁻². High heat flows are associated with Carboniferous granite intrusives and lower than world normal values are associated with the Paleozoic orogenic belt. A plot of heat flow versus heat production places Newfoundland in the same thermal province as Maritime Canada and the Eastern United States.

Analysis of heat flow data gathered during Lorex-79 by A.S. Judge has revealed an interesting pattern. Values determined for the Makarov Basin appear to be similar to previous values in the Canada Basin, whereas the Fram Basin yields rather higher values consistent with its supposed younger age. Heat flows determined on the Lomonosov Ridge are quite variable, due to complex topographic and sediment conditions, but they appear consistent with a basement composed of rocks of very low heat generation.

(b) Geothermal Energy

The well on the campus of the University of Regina has twice been accurately logged for temperature. It has also undergone pumping tests, and water samples have been examined for chemical content and corrosive properties. The bottom-hole temperature is lower than originally thought by about 8°C. This is not completely understood, since this well seems to be cooler than others in the same general area. The explanation may lie in the complex interaction of water movement, salt solution and basement heat flow.

At Mt. Meager diamond drilling for temperature and other observations has been continued by B.C. Hydro, with partial funding and technical advice and assistance from EMR. Examination of the cores has indicated that there is an active hydrothermal system below the south flank of Mt. Meager, but the energy potential is not yet known.

At Mt. Cayley, also in the Garibaldi Volcanic Belt, geological mapping, a resistivity survey, and some shallow drilling in easily accessible areas indicate good prospects for another geothermal resource area.

In the Okanagan area two holes have been drilled to test the temperature gradients near two small Tertiary sedimentary basins. It is thought that some of these basins may contain exploitable quantities of warm (50°C - 180°C) water. Evidence of lateral migration of warm water, causing disturbance to the vertical heat flow field, is available in a similar basin.

A small scale project to assemble geothermal data in Nova Scotia and Prince Edward Island has begun. This is part of an attempt to examine the geothermal potential of the Atlantic region, an area of marginal geothermal promise but high economic energy need.

(c) Permafrost Studies

The acquisition, preservation and eventual abandonment of Arctic drillholes for deep temperature observations has been continued by A.S. Judge, A. Taylor and M. Burgess, with the addition of sites in the Cameron Hills, south of Great Slave Lake, in the Keewatin and in the southern Yukon and the abandonment of several sites in the High Arctic and Mackenzie Delta. Several sets of results have been analysed in greater detail to determine the natural stability of the permafrost, the undisturbed terrestrial heat flow, and the palaeoclimatic and geomorphic implications of the results. Using drillholes to 450 m in Northern Québec, the uncorrected terrestrial heat flux was shown by A. Taylor and A.S. Judge to increase by one third between the top and bottom of the holes. The contrast was used to develop a simple model of surface temperature history over the past 85,000 yrs.

Although no new offshore permafrost drilling was undertaken in the Beaufort Sea, research continued through a summer cruise by A.S. Judge and V. Allen on the CCGS Nahidik during which some 40 cores were taken and 35 thermal gradiometer penetrations were completed on the continental shelf. The stations occupied lay primarily within and to the east of the Kugmallit Trough. During station work in the vicinity of a pingo-like feature, "the Admiral's Finger", one naturally frozen core was recovered and some bubbly ice with mud attached was freed from the sea-bottom.

Under Energy Research and Development funding, A.S. Judge has continued to monitor contract investigations into gas hydrates and the behaviour of soil moisture in cold regions and the implications for industrial development. Studies have included the use of time domain reflectrometry (TDR) techniques to determine unfrozen water contents of frozen soils, a study of heave processes and ice segregation in the presence of temperature gradients, and a study of isotope redistribution of oxygen and hydrogen due to permafrost formation and changes in climate. These largely laboratory investigations complement shallow ground temperature investigations by A.S. Judge, M. Burgess and A. Taylor, at an artificially drained lake site in the Mackenzie Delta. At the lake site, drained in the summer of 1978, the bow-shaped, up to 30m thick unfrozen zone beneath the lake has frozen back to a depth of 4m and the mean temperature has fallen by 2°K. The water content of the unfrozen zones is calculated to be sufficient to raise a pingo 60m in

diameter and 4m high, liberating 1.7×10^{14} Joules of heat during the freezing process.

(d) Tectonophysics

H.S. Hasegawa is summarizing available data on intraplate stress in eastern Canada. The relatively greater scatter in the direction of the maximum horizontal component of stress in eastern Canada compared with measurements in the eastern United States may reflect the importance of remnant stresses from past tectonic events in the Canadian Shield.

4. Pacific Geoscience Centre

(a) Lithospheric Studies

G. McMechan, while on leave at Stanford University, worked on inversion of refractions, free-surface multiples and dispersive waves by using wavefield transformations. These transformations have been successfully applied to Canadian and American seismological data in both land and marine configurations.

G. McMechan, while on leave at the USGS, Menlo Park, worked on a formulation for producing synthetic high-frequency seismograms for laterally inhomogeneous structures. The method was successfully used in the interpretation of refraction data from the Imperial Valley, California.

G. McMechan has programmed full wave solutions to wave propagation in laterally varying media by finite differences. Both acoustic and elastic solutions were included.

R.D. Hyndman, with R.M. Clowes, N. Bird and J. Horne (University of British Columbia) and B.D. Loncarevic (Atlantic Geoscience Centre), has carried out the offshore part of a major seismic experiment (VISP-80) to determine the deep structure beneath the continental margin of southwestern British Columbia. The whole program involved 9 different institutions, and had large shots offshore and onshore, recording onshore and with 8 ocean bottom seismometers (OBS) offshore. In addition to refraction lines perpendicular and parallel to the coast, a deep reflection experiment was undertaken with a commercial type reflection array on land, using both borehole explosive shots and a 32 litre airgun source.

R.D. Hyndman, with R.M. Ellis, R.M. Clowes, N. Bird and J. Horne (University of British Columbia), is analyzing data from temporary land station and OBS offshore arrays, and explosive profiles to determine the distribution of microearthquakes on the Queen Charlotte fault zone and the structure across the Queen Charlotte Islands continental margin.

(b) Seismological Instrumentation

The Western Canada Telemetered Network (WCTN)

Hardware and software is a modified copy of the ECTN. WCTN currently consists of four stations, with an expansion to seven stations at a later date. The operating stations are at Patricia Bay (Sidney), Pender Island, Alberni and Haney. The former Haney station was relocated and converted from telephone to radiotelemetry. New stations are located near Campbell River, Sechart and in the Renfrew - Jordan River area, and will become fully operational in 1981. The Pender Island station is being moved to Saturna Island. Two channels of the planned UBC network will also be received and incorporated into WCTN via the Saturna repeater station.

II Physics of the Earth's Interior

(a) Heat Flow and Heat Production

E.E. Davis has completed a study of the nature of heat flow variability over young oceanic crust fully covered by low permeability sediments but near an outcropping basement ridge. The results contain information concerning the efficiency of hydrothermal heat transport in the oceanic crust.

E.E. Davis with J. Sclater (Massachusetts Institute of Technology) and C. Lister (University of Washington), has completed a detailed heat flow field study over old (up to 165 million years) oceanic lithosphere in the northwestern Atlantic. The results should provide information about the thermal aging of old oceanic lithosphere, and about the causes of heat flow variations in extremely old ocean basins.

R.D. Hyndman, with T. Lewis, J.A. Wright (Memorial University) and M. Burgess (EPB, Ottawa), has analyzed and modelled heat flow measurements in the seafloor and on land across the Queen Charlotte fault zone, and found a smooth transition from very high deep sea values to low land heat flow. No significant frictional heat appears to be generated on the fault.

T. Lewis has set up a new gamma ray spectrometer system for measurement of radioactive heat production in rocks. An EG and G Ortec 7010 data acquisition system (16K) is connected to a multi-user PDP-11/40 computer for analysis. In addition to rapid routine measurements, the system permits studies of uranium series disequilibria.

T. Lewis has measured the heat production of a large number of rock samples from the Coast Crystalline Complex, to be associated with geothermal heat flow measurements in northern B.C. coast inlets. The values are generally low, similar to published values to the south.

T. Lewis with E.E. Davis has measured the radioactive heat production in Deep Sea Drilling Project sediment cores from off the west coast of North America to determine the contribution of the sediments to measured heat flows.

T. Lewis has determined more high heat production from the Lac du Bonnet batholith in eastern Manitoba as part of the radioactive waste disposal program.

(b) Geothermal Energy

T. Lewis has measured heat flow in a number of boreholes in the White Lake Basin (Tertiary Penticton Outlier), southern British Columbia. The heat flow indicates systematic deep water movement that may provide a hot water geothermal resource.

T. Lewis and L. Werner have measured heat flow in two holes drilled adjacent to two other Tertiary Basins of southern B.C. that have potential for a hot water geothermal resource.

T. Lewis, J.G. Souther (Geological Survey of Canada) and B.C. Hydro personnel have been involved in geothermal measurements in two areas associated with young volcanic rocks that have geothermal steam energy potential.

(c) Tectonophysics

E.E. Davis and D. Seemann, have compiled a suite of thirty-five seismic reflection profiles which cross the continental margin of western Canada at a quasi-regular spacing of about 25 km.

E.E. Davis and R.P. Riddihough have completed a geophysical data compilation and interpretation of the Winona sedimentary basin, where extremely thick (up to over 7 km) accumulation of young (2 million years and younger) turbidite sediments has become highly lithified by carbonate cementation.

E.E. Davis has completed a study of a suite of seismic reflection profiles in the area of the Dellwood Knolls which indicates that thin sea floor lava flows can extend tens of kilometres from their sources.

G.C. Rogers has proposed that the concentration of seismicity in the McNaughton Lake region of the Canadian Rockies may be due to a hotspot in the mantle.

G.C. Rogers has been studying the earthquakes in the subducted plates under southern Vancouver Island and the Puget Sound region. A model has been devised that explains the diversity of focal mechanisms and the seismicity rate.

D.H. Weichert and R.D. Hyndman have compared the rate and pattern of seismicity in Puget Sound and southernmost Georgia Strait with deformation estimates from plate models, from geodetic surveys and from the deformation of sediments along the continental rise. The different deformation estimates are found to be consistent, but the seismicity estimated through seismic moment calculations is much greater than that observed.

R.D. Hyndman and D.H. Weichert have refined the technique of estimating average fault slip rates from contemporary seismicity, integrating over magnitude-frequency of occurrence-recurrence relations and employing empirical moment-magnitude relations. The average slip rates on the Queen Charlotte fault zone, the Juan de Fuca ridge system transform faults and the Gulf of California faults from the seismicity are all in good agreement with the estimates from plate models.

6. University of Alberta

I Seismology

(a) Theoretical Studies

Although ray synthetic seismograms are enjoying enormous popularity, they represent, at best, only a convenient approximation of the total seismic field due to the fact that a finite number of rays are used. Thus, alternative methods must be employed for checking the accuracy and range of applicability. One of the most promising methods in this category is the Alekseev-Mikhailenko method. This method was developed by B. Mikhailenko of the Computing Center of the Siberian Branch of the Soviet Academy of Sciences, who was a guest of F. Hron and the Institute for six months during the past year.

His method models the total seismic field by a very efficient combination of analytical and numerical techniques. Making use of the computer software specially developed for the Alekseev-Mikhailenko method, several thousand synthetic seismograms were computed for a large variety of complex geological models. It was at this stage that a new wave, denoted by S^* , was discovered in the numerical solution of Lamb's problem.

Some non-geometrical effects of seismic wave propagation were investigated by L. Marks and F. Hron. This project was initiated as it had been known for a long time that the geometrical ray theory, which formally corresponds to the zero-order approximation of asymptotic ray theory, cannot explain all features in the seismic wave field. Since the results are the first ever reported they represent a stepping stone in future studies concerning the accuracy of seismic numerical modelling.

E.S. Krebs and F. Hron continued their studies of seismic waves in anelastic media. The linear theory of viscoelasticity has been used to model anelasticity of real media. Synthetic seismograms for teleseismic body waves and for spherically divergent seismic waves were computed. The seismograms for the anelastic layers exhibit amplitude attenuation and waveform spreading seen on actual field records.

P.F. Daley and F. Hron have developed a hybrid technique called the ray-reflectivity method. It uses matrix formulation to account for scattering of seismic energy by the stacks of thin layers and asymptotic ray theory to consider the influence of individual thick layers.

R. Chan and F. Hron have initiated the basic research to study diffracted arrivals in elastic wave propagation due to rapidly changing geometrical features of boundaries or elastic properties of the media. Solutions are expected to be found by employing the boundary layer method and the method of successive approximations by the integrals of the Sommerfeld-Malyuzhint type.

C. Athias, Yu Kan Hin and E.R. Kanasevich are working on finite difference methods for seismic wave propagation in an inhomogeneous medium. Emphasis is being placed on the direct problem.

M. Hron and M. Razavy are working on the inverse problem of wave propagation in an inhomogeneous medium. With the assumption that the reflection coefficient as a function of travel time is known at N points, the logarithmic derivative of the wave amplitude can be fitted at these N points using Thiele's reciprocal difference method. By comparing the logarithmic derivatives found from the fit and calculated from the difference equation, the wave velocity can be determined at N points. This method has been tested on exactly solvable models and the results indicate that the inversion is stable and accurate for small N ($N < 20$) but becomes unstable for larger N values ($N > 50$).

E.R. Kanasevich, F. Abramovici and P. Kelamis are working on the exact solution for seismic wave propagation in a layered medium. The technique is a development from the method of Pekeris and the Cagniard-de Hoop method. Particular emphasis is being made on studying the near field from impulsive SV and SH sources. The exact solution is decomposed into generalized rays and an approximate method of incorporating attenuation has been developed.

(b) Experimental Studies

Cooperative crustal seismic refraction and reflection studies continued as part of the CO-CRUST program (CONsortium for Crustal Reconnaissance Using Seismic Techniques). The consortium undertook a large scale refraction study on Vancouver Island during the month of August, 1980. Refraction arrivals were recorded from three shot points along the island, and from a series of shots in Jervis Inlet and in the Pacific Ocean off the west coast of the island. The experiment was designed to determine crustal structure under the island and to examine the transition from continental to oceanic crust. In addition a short multifold-coverage reflection line was recorded with shot points both on the island and in the water of Alberni Inlet, in order to test the

feasibility of using reflection seismic methods under these crustal conditions and to compare recording from water shots using an airgun and land shots using conventional explosives.

From the University of Alberta, E.R. Kanasewich and G.L. Cumming took part, assisted by C.H. McCloughan, L.K. Tober and P.G. Kelamis. We recorded with three single station instruments and our twelve channel refraction instrument.

E.R. Kanasewich, J. Samson and G. Yang are developing methods of polarization analysis of multi-component or array seismic data. The method employs unitary matrices to find pure polarized states as developed in quantum mechanics. The polarization filter is quite successful in suppressing random noise and enhancing waveforms of arbitrary shape.

Seismic refraction techniques have been used in southern Saskatchewan by E.R. Kanasewich and Z. Kazmierczak to study the crust. There is support for the existence of one or more major crustal faults in southern Saskatchewan running in the N-S direction. The depth to the Mohorovicic discontinuity in southern Saskatchewan varies from 40 to more than 50 km. The pattern of crustal thickness changes in southern Saskatchewan indicates the existence of Precambrian block faulting with north-south trends in the east and possibly complex NE-SW trends in the west.

C. Rebollar, E.R. Kanasewich and E. Nyland are studying the seismicity of the Rocky Mountain foothills in the vicinity of the Strachan gas field near Rocky Mountain House.

II Physics of the Earth's Interior

During 1980 E. Nyland and his Mexican colleagues began monitoring a small but very deep (280 m) reservoir by means of a geodetic network at Chicoasen in southeast Mexico. To this time the filling of the Chicoasen reservoir has not had a detectable effect on the geodetic network. There has been only low level induced seismicity.

E. Nyland and R. Lamoreaux believe that the segmentary nature of subduction of the Cocos plays a significant role in the seismicity. Lamoreaux is testing this notion with a review of, and preparation of new, focal plane solutions for carefully chosen pairs of earthquakes in southeast Mexico. If it is in fact correct it could indicate the relative stress between adjacent segments; which segment is likely to have a large event soon; or migration patterns.

While on sabbatical at U.C.S.D. E. Nyland continued his collaboration with the Mexicans at UNAM and at the suggestion of J. Brune assisted CICESE in the installation of the first network specifically designed to monitor movement on the Pacific North American plate boundary south of the Mexico-U.S. border. This led to the first data ever acquired for geodetic strain changes due to earthquakes on the Pacific North America plate boundary south of the U.S.-Mexico border. The results are surprisingly different from the results of surveys nine months earlier in the Imperial valley.

T.J.T. Spanos has developed a macroscopic description of immiscible displacement in a porous medium. This theory yields consistency with the empirically observed initial conditions, boundary conditions and breakthrough conditions. Perturbation analyses have been applied to this theory to examine the stability of the flood front during immiscible displacement. This work is being done in order to obtain new tools for modeling the fluid dynamics which occur in-situ during heavy oil recovery.

F.W. Jones and J.S. Rogers of the Low Temperature Group in the Department of Physics and M. McLaren have constructed ten Stacey-type mercury tiltmeters to be used for measuring Earth tides and local tilts. Two instruments have been in operation at the Leduc Observatory since May, 1979. Two instruments were installed in Victoria in December, 1979 and have been operating since that time. In June of the past year two instruments were installed at Penticton, B.C., so that simultaneous recordings are now being carried out at three stations in Western Canada. Also, during the summer of the past year two instruments have been used in the field to test surface mounting at a site in Edmonton. Work is now beginning on the data so far recorded.

Last year J.S. Bell and D.I. Gough reported that many oil-wells in Alberta exhibit spalling of the walls, known as break-outs, which elongate the holes with the longer axes aligned northwest-southeast. This alignment is observed over an area in excess of 4×10^5 km², in siltstones, sandstones, carbonate sediments and one shale, through the stratigraphic column from Devonian to Cretaceous. They have now added new data from oil-wells in Alberta and northern British Columbia and have shown that the break-outs, and by inference the stress orientations, are consistent through much of the western Canadian sedimentary basin. Evidence from hydraulic fracturing in the Rocky Mountains foothills of west central Alberta, and from steam-injection fracturing in eastern Alberta, supports the view that σ_1 is aligned NE-SW. The break-outs are consistent with either a thrust stress field or a strike-slip stress field, but the fractures formed by excess pressures in wells favour the latter.

C. Fordjor is making an intensive study of the break-outs in the Pembina oilfield of western Alberta with the aim of securing more quantitative and statistically defined knowledge of the break-out phenomenon and of the stress field and its local anomalies.

7. University of British Columbia

D. Au and R.M. Clowes have completed the interpretation of an extensive set of marine seismic data obtained from three 3-component ocean bottom seismometers (OBS's) deployed around the Nootka fault zone, the boundary between the Juan de Fuca and Explorer plates. P- and S-wave velocity-depth models are interpreted from the observed data with the aid of WKBJ synthetic seismograms and an approximate approach for calculating synthetic seismograms in laterally inhomogeneous earth models. The results show considerable differences in crustal structure among three reversed profiles. The results are consistent with laboratory measurements on ultramafic rock samples from ophiolite complexes.

B.N. Bird, J.R. Horn, R.M. Ellis and R.M. Clowes are continuing interpretation of a set of onshore-offshore seismic data recorded on OBS's and land stations deployed in the southern Queen Charlotte Island region during a collaborative program with the Pacific Geoscience Centre. The area is of particular interest as there is direct ocean-continent lithospheric contact along the transform fault zone. Interpretation methods such as synthetic seismograms for both laterally homogeneous and laterally varying earth models are being applied. In addition, the entire data set is being analysed using a new linear programming approach to time-term analysis. Preliminary results indicate an oceanic mantle refractor with a velocity of 8.1 km/s at a depth of 10 km and dipping at 6° toward the island from the outer scarp of the fault zone.

B.N. Bird has developed a linear programming approach to time-term analysis of seismic refraction data. The method is more adaptable than previous ones. For example, minimizing the L_1 norm of the misfit

errors produces a best-fit model; maximizing (or minimizing) the sum of the time terms gives the deepest (or shallowest) models which fit the data. As well, the method has been adapted to allow for refractor anisotropy. A set of travel times for the P_n phase from the northeast Pacific is used to exemplify the application of the method.

R.M. Ellis, G.D. Spence and R.M. Clowes coordinated VISIP 80 (Vancouver Island Seismic Project) on behalf of the participating COCRUST institutions - the Universities of British Columbia, Alberta, Saskatchewan and Western Ontario; the Pacific and Atlantic Geoscience Centres; and the Seismology Division, Earth Physics Branch. This onshore-offshore seismic project was carried out to study the oceanic-continental lithosphere transition from the deep ocean, across Vancouver Island and on to the mainland. A double reversed refraction line was run along the length of Vancouver Island; a second reversed refraction line was established up Jervis Inlet, across south-central Vancouver Island and extended offshore through the use of four OBS's. Two reversed marine explosive profiles, one parallel to the island and one coincident with the offshore part of the second refraction line were recorded on OBS's. A series of 32 litre airgun profiles were shot into each of the 8 OBS's deployed, two of which were placed on the continental shelf. A second phase of VISIP 80 was a feasibility study for deep crustal reflections on Vancouver Island. Using a 48-channel digital seismic acquisition system and explosive in drill holes, 1200% coverage along a 10 km line near the mouth of Alberni Inlet was achieved. In a unique experiment, the 32 litre airgun was fired along a 10 km track directly offshore from the 48 channel system and seismic data recorded for six traverses along the track. Initial playbacks of both sets of reflection data indicate that coherent reflections from within the deep crust were obtained.

R.M. Ellis and R.M. Clowes are continuing their interpretation of a detailed reversed refraction profile recorded across the Rocky Mountain Trench between the Sullivan Mine in the Purcell Anticlinorium and Kaiser Resources coal mine in the western Rocky Mountains. The application of interpretive methods for laterally varying structures is required.

R.M. Clowes, while on study leave in Denmark, became the "Danish" representative for an international seismic project. During August 1979, the Scandinavian lithospheric profile (Fennolora 79) was recorded along a 4000 km line extending from north of Sweden to the German Democratic Republic. Danish scientists occupied two stations on the island of Bornholm, an important location because the Scandinavian shield is exposed to the north while the German sedimentary basin lies to the south. R.M. Clowes will concentrate on an interpretation using those seismograms with shot-receiver distances up to 500 km recorded in Bornholm and in southern Sweden.

In June and July 1980, R.R. Coenraads and R.M. Ellis carried out a microearthquake survey about Sullivan Mine to determine if faults could be delineated in the mine environment using the distribution of hypocentres. The data set of 352 events, each recorded on 4 to 7 digital seismographs, is presently being analysed in an initial stage to separate mine related microearthquakes, regional earthquakes and mine explosions.

R.M. Ellis and R.D. Hyndman (Pacific Geoscience Centre) have completed a microearthquake study along the Queen Charlotte Fault Zone using both ocean bottom and land based seismographs. Eleven events were located with magnitudes from 0.5 to 2.0, ten of them beneath the landward of the two steep slopes, some 5 km off the coast of the southern Queen Charlotte Islands. The earthquake and other geophysical data are consistent with a near vertical fault zone having mainly strike-slip motion.

A model including a small component of underthrusting in addition to strike-slip faulting is suggested to account for the approximately 15° difference between the relative motion of the North America and Pacific plates from plate tectonic models and the strike of the margin. One event was located about 50 km inland of the main active zone and probably occurred on the Sandspit fault.

8. University of Manitoba

I Seismology

The vertical component (1/2 Hz high output detectors) of signals from open pit mine blasts at the Griffith Mine (Ear Falls, Ontario) was recorded at 50 locations along Highway 105 from Ear Falls to Red Lake. The principal targets were the boundary between the English River and the Uchi subprovinces and crustal structure in the latter. Digital data processing is underway. Investigators: D.H. Hall, W. Moon and B. Maxwell. Supported by Ontario Geological Survey.

W. Moon and Wanda de Landro are currently working on the detailed interpretation of 1977 and 1979 CO-CRUST refraction data along the Churchill-Superior boundary zone. Herglotz-Weichert type inversion, ray tracing and WKBJ synthetic seismogram methods are being used.

W. Moon is working on a theoretical study of reflectivity from velocity gradients for deep and shallow crustal reflection seismic interpretations.

W. Moon is testing the usefulness of synthetic seismograms for the detailed study of multiples from unusual geological sequences, as well as vertical velocity profiling.

9. University of Saskatchewan

I Seismology

Z. Hajnal continued the analysis of the 1979 CO-CRUST (Consortium for Crustal Reconnaissance using Seismic Techniques) crustal refraction and reflection data. The refraction data interpretation revealed distinct crustal features in the Churchill and Superior tectonic provinces as well as in the interconnecting boundary zone. The combined analysis of the 1977-79 near vertical reflection sections shows that the crust is structurally disturbed at the western margin of the Superior province and in the easternmost segment of the Nelson Front.

Z. Hajnal and B. Reilkoff developed a static correction technique which was successfully adapted to low signal to noise level multi-fold high resolution reflection data. When the method was applied to data collected in the Athabasca basin of northern Saskatchewan, the final sections were significantly better in quality than when processed with standard techniques.

A. Hajnal, M.R. Stauffer and A. Congram began petro-physical analysis of the Athabasca sandstone in the Mid-West Lake area of the Athabasca basin. The rock mechanic and acoustic characteristics of several sets of borehole samples are determined by laboratory measurements. These results are correlated to very detailed geological features of the same samples. Synthetic seismograms computed from the above information will establish the seismic behaviour of the Athabasca sandstone over commercial uranium deposits.

A detailed laboratory investigation of the seismic reflection characteristics of the Lloydminster heavy oil deposits of Saskatchewan was started by Z. Hajnal and M. Lomas. Sonic log characteristics will be correlated to important geological features and their variation in the heavy oil deposit section of the Mannville sandstone. Synthetic seismogram analysis of these data will reveal the resolution capability of the high frequency seismic reflection technique in this environment.

10. University of Toronto

I Seismology

In 1978, C.H. Chapman developed a new method for computing synthetic seismograms. A very useful approximation to this method, the WKBJ seismogram, has been fully developed. A versatile computer program has been written to compute WKBJ seismograms; it has been widely distributed and is used by many institutes.

Together with J.A. Orcutt of the Scripps Institution of Oceanography, C.H. Chapman has developed an inversion technique for oceanic refraction data. The method has been tested using data from the 1959 Fanfare cruise of Scripps Institution. These data had been previously interpreted by trial-and-error using reflectivity synthetics (Spudich and Orcutt 1980, *J. Geophys. Res.*, 85, 1409). For the trial data, the method converges rapidly to a model close to Spudich and Orcutt's, establishing that even for very band-limited data the technique works, and that their interpretation was very accomplished. In order to run the program interactively with larger data sets and more parameters, the iterative procedure has been programmed for an array processor (Floating Point System AP120-B on a VAX 11/780 host computer).

The WKBJ seismogram program has been extended to models with lateral variations by C.H. Chapman and R. Drummond. To expedite tracing the plane waves, the model is approximated by linear functions in each triangle of a grid. This method was developed by Moon and Marks (University of Alberta) and is very efficient because analytic solutions can be used in each triangle. In the WKBJ seismogram, the (small) caustics formed by the gradient discontinuities are not troublesome as they are smoothed automatically. Initial tests of the computer programs are encouraging. Currently, the program is being refined and the approximations reduced.

The slant-stack (Radon transform) technique for analysing data has been extended by C.H. Chapman to point source data on a plane or spherical model. Although the technique has been widespread since its development in 1978, only approximate results have been used. P. Cary is developing numerical techniques for performing the exact, generalized Radon transforms. This can be used for the direct or inverse problems.

Slant-stacked data represent the impulse response of the medium to plane waves. Exact inverse methods exist for plane wave data provided they are not totally reflected. Unfortunately, these techniques are often unstable. N. Bregman is investigating an inverse technique originally developed by Bailey (University of Toronto) for geomagnetic data. Using the redundant plane-wave data available in a slant-stack section, it is hoped to stabilize the technique.

With J.H. Woodhouse (Harvard University), C.H. Chapman has investigated the symmetries of the elastic-gravitational system. The symmetries of the equations and solutions had previously been noted for the elastic system in plane geometry. These have been extended to the elastic-gravitational system in spherical geometry.

With R. Buland (U.S. Geological Survey), C.H. Chapman is developing a rapid, versatile method for travel-time table computation and interpolation. The tables can be modified rapidly as perturbations are linear in perturbations in the model depths (not velocity). The tau function is calculated and is easily interpolated as it is monotonic, continuous and single-valued. The travel-times at any range are found from stationary values of $\Theta(p,x) = \tau(p) + px$, rather than interpolating travel-time tables, $T(x)$.

II Physics of the Earth's Interior

(a) Glacial Isostasy: Analysis of the free air gravity anomalies associated with the main centres of (Würm-Wisconsin) deglaciation has been completed by W.R. Peltier and P. Wu. Results from Canada, Fennoscandia, and the Antarctic are consistent and provide a strong constraint upon the viscosity of the mantle beneath the seismic transition at 670 km depth. An upper bound on the viscosity in this region is about 10^{23} Poise (cgs units).

(b) Mantle convection: Work has continued on the new theory for sea floor flattening mentioned in last year's Bulletin (Peltier and Jarvis). Observations of ocean floor bathymetry and heat flow show that the former obeys an $AGE^{-1/2}$ law out to ocean floor ages of about 7×10^7 yrs but flattens thereafter, whereas the latter follows an $AGE^{-1/2}$ behaviour without substantial deviation. We have shown such behaviour to be completely explicable as a consequence of partial internal heating in a convective circulation at high Rayleigh number.

(c) Mantle rheology: Work on the development of a complete and self consistent linear visco-elastic rheology for the mantle has continued. It has been shown (Peltier) that a generalized Burger's body is capable of fitting the entire range of geodynamic observables which extends over time scales from seconds to hundreds of millions of years.

11. University of Western Ontario

I Seismology

The propagation of seismic waves through earth models with slightly random lateral inhomogeneities superimposed on one composed of layers with vertical velocity gradients was investigated by R.F. Mereu and S.B. Ojo. The resulting models show short discontinuous reflectors scattered about at various depths throughout the model, and are thus in agreement with many deep seismic reflection experiments. Many of the numerical experiments which modelled the random crust produced a Pg segment and P* segment with an apparent Conrad discontinuity at a depth of 10 to 20 km, this apparent depth being related to the correlation distance.

A series of coherency measurements done on array recordings of earthquakes at various distances showed that large lateral and vertical variations in complexity exist for different ray paths through the Earth with the region below the 650 km discontinuity in the mantle tending to be much simpler than the region just below the lithosphere. The results also showed that much less scattering of seismic energy occurs in the upper mantle under oceans compared to the upper mantle under continents.

During the summer of 1979, R.F. Mereu and S.B. Ojo participated with the University of Saskatchewan, the Earth Physics Branch, EMR, and the University of Alberta in a major crustal seismic refraction experiment in Southern Saskatchewan and Manitoba. Recordings were made along three 280 km long seismic refraction lines which were designed to study the structure of the crust across the Superior-Churchill geological boundary. In this experiment seven U.W.O. portable recorders were used

to obtain 84 vertical and 56 horizontal seismic traces. The data from this experiment are at present being compiled and analysed.

Further improvements were made by J. Brunet and R.F. Mereu on the development of a set of new portable seismic recorders which feature a low power RCA 1802 micro processor for programmed timing and control. Five of these units were employed along with some older models in the Superior-Churchill 1979 experiment. An additional 4 units are now under construction for future use.

The University of Western Ontario seismic array near London, Ontario continued to operate during the past year. As a result of small earthquakes which were detected in 1978 in an area a few miles east of Woodstock, an additional station was added near Gobles, Ontario. Observations of additional small tremors (magnitude 2.8 on December 30, 1979 and 1.9 on February 23, 1980) were made. An analysis of the results showed that these events both occurred in the small oil field near Gobles, Ontario, and were probably triggered by secondary oil recovery activities in the field.

Temporary seismic arrays were operated at sites traversing the margin of the West African Craton between Kedougou and Missirah in Senegal between October 1978 and March 1979, by the University of Leeds and O.R.S.T.O.M. Adaptive processing shows that azimuth and slowness anomalies for P waves are azimuth-dependent and are much greater for the arrays on the Mauritanide orogenic belt than are observed on the Craton. Other studies at UWO on these data involve spectral analysis, polarization study and modelling of slowness anomalies in terms of lateral deep structure. Together with delay time analyses, ray tracing and synthetic seismogram studies at Leeds, these results lead to recognition of lower-velocity structure beneath the mobile belt than beneath the Craton, differences persisting to several hundred kilometres depth. The margin of the Craton may be sharp, even at mantle depths.

The circum-Pacific seismic belt was divided into 36 regions by I.F. Jones and L. Mansinha. The time and location of the epicentres of large earthquakes showed that twelve of the 36 regions had perceptible migration trends. The onset and termination of these trends correlate well with an increase or decrease of seismic activity. The physical significance of these results is currently being examined.

Confusion exists in the current literature between build-up time, inter-event time, and recurrence time, and their relation to seismic moment. An attempt is made to clarify this issue, and to critically examine the assumptions made in relating these parameters. In particular, it is shown that a linear or cubic relation between the seismic moment and the build-up time is incompatible with the assumption that the build-up time is linearly related to the inter-event time.

II Physics of the Earth's Interior

(a) Heat Flow

A.E. Beck reports that with new equipment it is possible to obtain borehole logs which allow resolution of temperature gradients differing by 0.1 - 0.2 mK/m over a distance of about 0.5 m at a logging rate of 8 m/min. Since such a detailed profile of temperature gradient versus depth is easily obtained, any disturbances to the equilibrium gradient can now be readily identified.

Some analytical techniques are being tested to try to identify the forms of surface temperature variation which disturb the equilibrium regime in boreholes to depths of more than 100 m; a polynomial curve is

fitted to the observed temperature gradient and from the real roots of the first and second derivative equations of this fitted curve, estimates of the types of surface thermal disturbances are made.

Application of these procedures to a well characterized borehole indicates that there were increases in temperature of 1°K approximately 250 years ago, 3.6°K approximately 25 years ago and 5.0°K approximately 8 years ago. The first disturbance may be associated with the ending of the "little ice age" while the last two are associated with the completion of large buildings nearby in 1958 and 1967.

(b) Properties of Rocks

Studies by H.H. Schloessin, C. Barker and C.J. Mwenifumbo were primarily concerned with the interactions between the thermoelectric properties of minerals and the thermal, electrical and mechanical aspects of geodynamic processes involving polycrystalline composites of minerals. Additional studies on this topic have been conducted to provide technologically useful information. Experiments were designed to determine the pressure, temperature, and time dependence of the Seebeck voltage of junctions formed by a selected combination of minerals. Oxides, network and sheet silicates as well as hydroxides have been investigated. The variations of the electrical resistivity and thermal conductivity of these minerals with pressure and temperature were measured separately. Pressure generally improves the thermoelectric efficiency of junctions involving p- or n-type or mixed semiconductors and reduces that of pure ionic conductors except for some sheet silicates.

Further high pressure and X-ray experiments were carried out on T.G.S. (triglycinesulphate) to explore its application as a thermal sensor and image converter.

Some simple laboratory experiments were conducted to examine several possible mechanisms which could be responsible for the phenomena of earthquake lights ("shine" or "lightning") which throughout historic times have been reported by eyewitnesses to precede and accompany the occurrence of earthquakes. Tribo- and thermoluminescence are plausible mechanisms for luminescence of the solid rock surfaces or suspended dust particles. Phosphorescence decay after ultra-violet exposure and thermoluminescence glow curves were investigated for a number of minerals.

If the strain buildup of an earthquake is considered from an original state of equilibrium, the seismic process may be described as a form of modified sawtooth function, rather than a step function. It has been found by P.Y. Shen and L. Mansinha that the time duration of strain accumulation is a factor in computing the seismic contribution to the wobble amplitude.

Unlike the result with the step function, a sawtooth excitation implies that earthquakes cannot be responsible for large scale permanent shift of the pole. Instead, the secular pole will execute a most probable path around a mean position, assuming stationary seismic activity.

The method of least-squares spectral analysis is applied by P.Y. Shen to the latitude and time variations observed at Ottawa PZT from 1956 to 1977 in an attempt to evaluate the amplitudes of the principal, semi-annual and annual nutation terms. Motions of the BIH pole, as well as seasonal variations in earth's rotation were removed prior to the analysis. The results are in good agreement with other determinations using different sets of data and confirm the dynamic effects of the liquid core of the earth. Attempt is also made to identify the nearly diurnal wobble of the earth. The results are in favour, but not conclusively, of its existence.

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III (A) GEOMAGNETISM

Compiled by: P.J.C. Ryall

1. Geomagnetic Surveys, Charts & Compilations
 - (a) Atlantic Geoscience Centre
 - (b) Earth Physics Branch
 - (c) Dalhousie University
 - (d) Geological Survey of Canada
2. Interpretation of Magnetic Surveys
 - (a) Earth Physics Branch
 - (b) Université Laval
 - (c) University of Manitoba
 - (d) University of Windsor
3. Magnetic Observations & Instruments
 - (a) Earth Physics Branch
 - (b) University of Alberta
4. Electromagnetic Induction in the Earth
 - (a) Earth Physics Branch
 - (b) University of Alberta
 - (c) University of Manitoba
 - (d) University of Victoria
 - (e) University of Toronto
5. Paleomagnetism, Rock Magnetism & Tectonomagnetism
 - (a) Earth Physics Branch
 - (b) Ecole Polytechnique
 - (c) Geological Survey of Canada
 - (d) University of Alberta
 - (e) Dalhousie University
 - (f) Université Laval
 - (g) Memorial University of Newfoundland
 - (h) University of Toronto
 - (i) University of Western Ontario
 - (j) University of Windsor
6. Bibliography

1. Geomagnetic Surveys, Charts and Compilations

- (a) Atlantic Geoscience Centre, Geological Survey of Canada

Some 3,383 line kilometers of magnetic data were collected on the continental shelf off northeastern Baffin Island and in parts of Davis Strait. These measurements were generally of a reconnaissance nature and were carried out aboard CSS HUDSON in conjunction with a seismic reflection and bedrock sampling program.

In a multiparameter survey program performed in cooperation with the Canadian Hydrographic Service and involving the Canadian Scientific Ships BAFFIN and HUDSON, 11,602 line kilometers of magnetic data were collected in Davis Strait and on the Labrador shelf. In Davis Strait, coverage consisted principally of east-west lines 38 km apart and extending from Baffin Island to Greenland. On the Labrador shelf, magnetic data were collected over Nain, Makkovik, and Harrison Banks, with lines 38 km apart roughly at right angles to the coast and extending out to the 500-meter contour.

All magnetic data were collected using Varian Model V-75 Proton Precession magnetometers connected to Barringer towed sensors.

Investigations were undertaken into the use of a commercially-available software package for the production of magnetic contour maps on in-house computer facilities at the Bedford Institute of Oceanography. With 'clean' data sets, results were satisfactory, and it is planned to

use this approach for the production of future editions in the Natural Resource Map series. The investigations, however, pointed out that much remains to be done in devising procedures for the preliminary editing and correcting of large quantities of magnetic data stored in computer files, particularly with regard to applications of the International Geomagnetic Reference Field to multi-year data sets. Some of this work is in progress, and is being applied to the backlog of Labrador Sea data now on hand.

Magnetic data collected over some 14,000 line kilometers on the Scotian Margin during a multiparameter survey in late 1979 have been readied for release to Open File by early 1981.

(b) Earth Physics Branch

(i) Magnetic Charts for Canada

A novel analytical approach was used to produce the magnetic declination (D) chart of Canada, from approximately 10,000 measurements in north component (X) and east component (Y) of magnetic intensity. These data were obtained primarily from aeromagnetic surveys by the EPB, Ottawa, from years 1969-1976. After applying corrections for secular variation, a gridding algorithm determined over 4,400 mean values of X, Y at 1 degree grid intervals over Canada. A smooth datum field was subtracted from these data and residuals X, Y obtained. For smoothing and interpolation between grid values, a spherical harmonic expression (SHE) to degree 180 was fitted to the residuals. Calculated SHE values were added to the datum values and D redetermined from these reconstituted X, Y values. A D-chart, scale 1:10 million, was plotted using Calcomp plotter techniques. The r.m.s. fit of the chart to the input aeromagnetic data is 130 nT.

A north magnetic pole position was determined for 1980 at 77.3°N and 101.8°W, just south of King Christian Island. The average secular motion of the pole since 1975 is 24 km per year north and 5 km per year west.

A magnetic chart of the Canadian Arctic for 1980, scale 1:7,500,000, was produced by EPB for the Canadian Hydrographic Service. The prime function of this chart is to depict those areas where the magnetic compass becomes erratic or useless as a navigational instrument. The chart also shows isolines of magnetic declination and isolines of the mean daily range of D. The latter isolines are based on daily range data from 6 northern Canadian observatories for the summer months of 1975, 1976 and 1977 (E. Dawson and L.R. Newitt).

(ii) Magnetic Repeat Station Survey

As part of a continuing study of magnetic secular variation, 12 repeat stations were occupied in British Columbia, Saskatchewan and parts of the NWT. The B.C. stations (6) were occupied by contract. The routine occupation and observation is similar to that outlined in Can. Geophys. Bull. V 32, p. 60, 1979.

(iii) Hudson Bay Surveys

Magnetic total intensity data from Hudson Bay ship-towed magnetometer surveys 1975, 1976, 1977 and 1978 have been corrected for transient and secular variations. Crossover analyses, before and after these variation corrections, confirm the validity of both correction techniques. Final crossover errors have been interpreted

in terms of navigational errors. A report on the reduction and correction techniques and navigational analyses is being prepared (G.V. Haines and R.L. Coles).

(c) Dalhousie University, Department of Geology

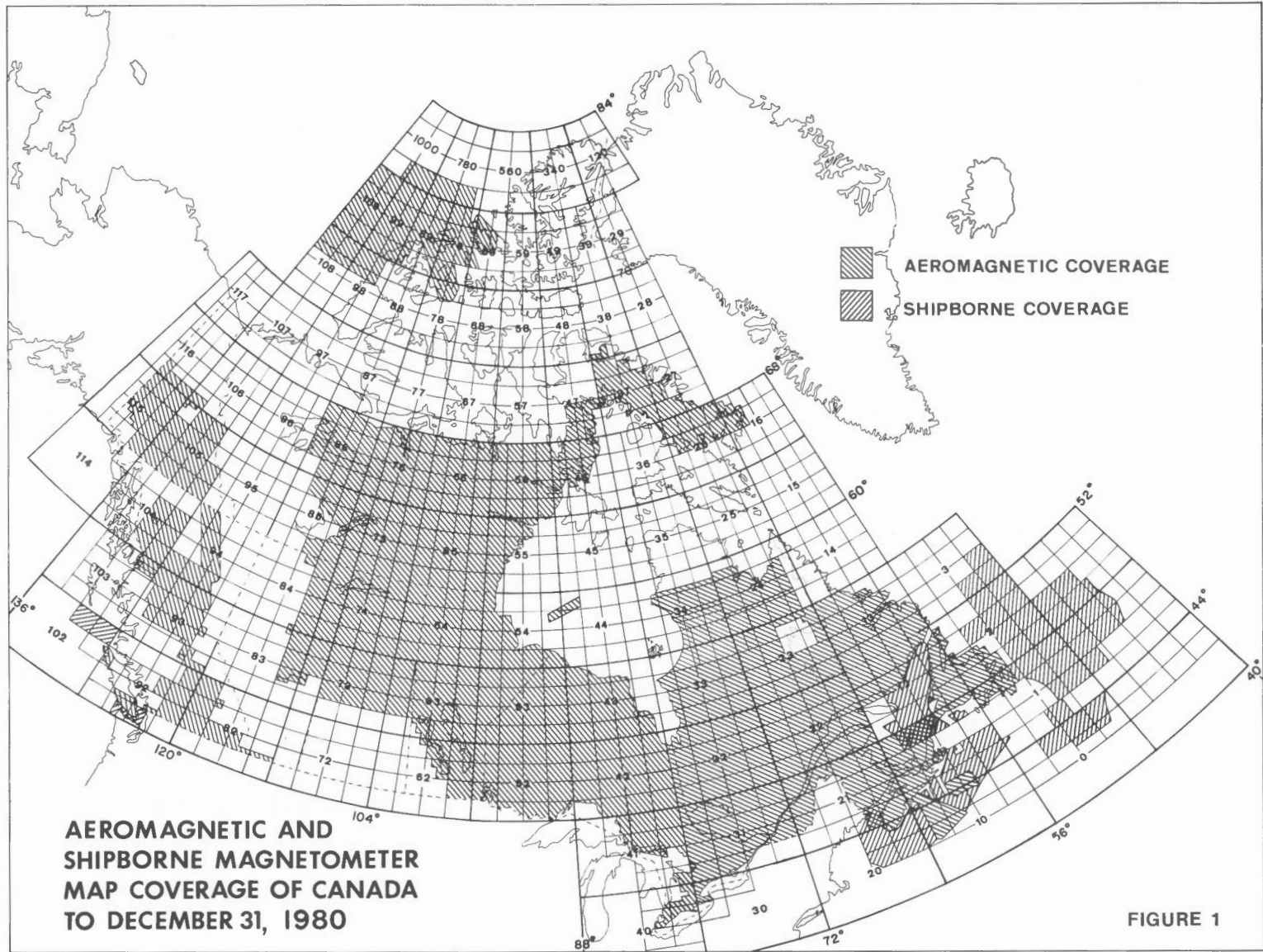
A total of 342 line kilometers of bathymetric and magnetic survey were carried out over a peak on the Mid-Atlantic Ridge at 36°25'N, 33°53'W. Positioning for the survey was by radar range and bearing from a buoy whose position was established by Satellite fixes. This survey was in support of a drilling programme carried out on the peak from CSS Hudson.

(d) Geological Survey of Canada - Regional Geophysics Subdivision

(i) The aeromagnetic survey of Canada continues and during 1980 56,102 line kilometers were flown in Labrador to bring the grand total flown in Canada since 1947 to 8,045,965 line kilometres.

A total of 491 aeromagnetic maps were published by the Geological Survey of Canada during 1980. Of these 27 were 1:25,000 high resolution, 430 were 1:50,000, 2 were 1:125,000 and 28 were 1:250,000 scale total field aeromagnetic maps. In addition 4 vertical aeromagnetic gradiometer maps were issued and included the first experimental colour maps. Figure 1 shows the published aeromagnetic and shipborne magnetometer coverage of Canada to December 31, 1980. The magnetic surveys depicted in Figure 1 include those carried out under the Federal/Provincial aeromagnetic survey scheme, those funded by the Provincial governments alone, and shipborne magnetometer maps issued by the Canadian Hydrographic Service.

High resolution aeromagnetic gradiometer surveys were flown by the GSC Queenair aircraft in the Val d'Or area of Quebec, the Flin Flon area of Manitoba, and the Underground Research Laboratory site of AECL at Pinawa, Manitoba. In addition reconnaissance lines were flown across the Athabasca Basin in Saskatchewan to ascertain the effectiveness of the vertical gradient technique in the deeper parts of the Basin and a strip was flown across northern Cape Breton Island, Nova Scotia, in order to compare the results of a measured vertical gradient survey with those calculated from the total field data obtained by an airborne geophysical survey contractor. The GSC aircraft has now flown approximately 50,000 line miles during the past 6 years and approximately 80 1:25,000 total field and 80 1:25,000 vertical gradient maps have been published by the Geological Survey of Canada. The aeromagnetic gradiometer results have been mainly utilized in detailed geological mapping programs and in the reconnaissance phase of four site investigations for the Canadian radioactive Waste Disposal Program. However, in 1979 a survey was carried out in the Wollaston Lake area of the Athabasca Basin over a number of important uranium properties. The release of the resultant data has resulted in the mining companies in the area becoming enthusiastic about the application of the aeromagnetic gradiometer technique for delineating the basement geology. This has come about in part because the ability to produce colour-contour total field and vertical gradient maps, using the Applicon plotter, has facilitated considerably the qualitative interpretation of the high resolution aeromagnetic survey data. In view of the fact that the aeromagnetic gradiometer technique has received wide acceptance, a technology transfer scheme has been implemented with the Ontario Geological Survey using DREE funding to have a commercial system built so that the service may be offered by a Canadian airborne geophysical survey contractor.



As a replacement for the North Star aircraft which carried out an aeromagnetic reconnaissance of the entire Labrador Sea and Baffin Bay during the period 1964-74, the National Aeronautical Establishment acquired a Convair 580 aircraft in 1976. Since that time the aircraft has undergone considerable modification and has been equipped with cesium magnetometers on both wingtips and at the top of the tail fin. In the new survey system all digital information is fed to an inboard Interdata 732 computer where it is transformed to the required format before being recorded on magnetic tape. For the first survey operation for the Geological Survey of Canada, the Convair 580 carried out an aeromagnetic reconnaissance of the Lomonosov Ridge during May 1979 as a contribution to the EMR Lorex project in the Arctic Ocean. A total of 4,400 line kilometers were flown in 1979 in obtaining 20 aeromagnetic profiles at 300 m flight elevation, 18 of which were flown orthogonally to the Lomonosov Ridge spaced approximately 37 km apart. One profile was positioned using the GNS VLF navigation system to cross the North Geographic Pole. There appears to be a zone of distinctive (1,000 gamma) anomalies parallel to and associated with the Lomonosov Ridge which are bounded on the southern side by an elongated low indicative of a graben-like structure. Because the line to line correlation of the anomalies was somewhat tenuous in the vicinity of the North Pole, seven additional lines spaced 5 km apart were therefore flown orthogonally across the Lomonosov Ridge in the vicinity of the Pole in 1980. The 1980 survey results demonstrated without reasonable doubt the existence of an elongated anomaly which is clearly associated with the Lomonosov Ridge indicating that it is in part composed of igneous rocks. In addition an aeromagnetic reconnaissance was commenced of the continental shelf of northern Ellesmere Island in 1980. Twenty-three lines spaced approximately 18.5 km apart were flown to the edge of the shelf. P.J. Hood and M.E. Bower presented the results of the 1979 and 1980 aeromagnetic surveys of the Lomonosov Ridge at the AGU meeting in Toronto in May 1980.

The Regional Geophysics subdivision has commenced a program to produce a 1:1,000,000 coloured aeromagnetic map series compiled from the existing aeromagnetic coverage of Canada. NTS sheets 64, 74 and 75 have already been digitized and plotted as part of a feasibility study. These showed clearly the tremendous amount of information and usefulness of colour maps at the 1:1,000,000 scale. NTS 65 has been digitized by another technique (contour tracing) and is currently being compiled. Digitization has commenced on NTS 66. It is hoped that the first maps in the series will be issued by the summer of 1981.

Compilation of a coloured Magnetic Anomaly Map of the Canadian Arctic on a scale of 1:3,500,000 is being undertaken by P.H. McGrath in cooperation with the Department of Indian and Northern Affairs. It is hoped to incorporate as much company data as can be released and the map is scheduled to be completed and be presented at the Arctic Symposium to be held in Calgary in June, 1981.

(ii) Interpretation of Magnetic Surveys

A quantitative interpretation of selected anomalies from both the total field and gradiometer data from the Wollaston Lake NAE/IAEA survey flown in 1979 has been made by D. Teskey. The main objective was to outline the depth and position of contacts between the Archaean basement and overlying metasediments, a knowledge of which is important in the exploration for uranium deposits in the Athabasca Basin. The resultant maps were compiled in colour contour

form utilizing the Applicon colour plotter and the resultant gradiometer map clearly illustrates both the superior resolution and the ability to delineate the finer structural detail of the gradiometer. This analysis was followed up by some ground susceptibility measurements in order to provide a greater understanding of the area. Preliminary results from this study were given in a paper (with L.J. Kornik) at the CGU/KEGS/AGU meeting in Toronto in May 1980.

As a contribution to AECL's Radioactive Waste Disposal program, an interpretation of the magnetic data for the area surrounding the proposed site of the Underground Research Laboratory (URL) near Pinawa in S.E. Manitoba was carried out. The URL site is located within the Lac du Bonnet Batholith, a granitic intrusion which has a heterogenous distribution of its magnetic elements. The area had been previously covered by standard sensitivity federal/provincial aeromagnetic 1 mile scale maps. Two sets of high sensitivity aeromagnetic vertical gradiometer and total field data are now available and a ground magnetometer survey was also completed over the site. In summary the magnetic data outlines the gross shape of the intrusion and its surrounding rocks, illustrates the presence and the trends of the major compositional units underlying the URL site and the presence of several northwest-trending magnetic linear features at the URL site.

(iii) Magnetic Observatories and Instruments (P. Sawatzky)

Ever since the GSC aeromagnetic vertical gradiometer survey system has been in operation, random shifts in the recorded data have occurred that have been extremely difficult to diagnose and eliminate. Those survey lines that had these shifts were thrown out and re flown; a rather costly business. It was eventually found that the major cause of the problem was related to the temperature control system affecting the R.F. section of the magnetometer head itself. Now that this has been corrected, it should be possible to operate under more adverse temperature conditions and many costly reflights will be eliminated.

A Herz Total 1A VLF EM equipment was installed in the Queenair prior to the beginning of the 1980 survey season. This required that a boom be constructed and mounted on the nose of the aircraft for the installation of the three mutually perpendicular antenna coils. The resultant in-phase and quadrature analogue signals are digitized and recorded via the existing digital data acquisition system. The system was operated during the entire survey season without any problem that related to the equipment or the installation. The data from these surveys is in the process of being compiled by the GSC Geophysical Data Processing Section.

The design of a new microprocessor-controlled system for the gradiometer has been progressing during the past year. Two new cards have been designed, one of which permits data from a small keyboard and two 8-digit thumbwheel switches to be entered into the microprocessor-controlled system. This card may be used to enter such information as project number, line number or other identifiers via the thumbwheel switches that do not require frequent updating. The keyboard would also permit the microprocessor to be addressed and controlled when the system is operating. The other card is designed to accept or permit data from any three external data sources, in groups of up to 32 bits per data source to be entered into the data acquisition system. This card is to be used to speed up data entry from external sources since it is designed to permit data to enter in the parallel mode rather than the serial mode, a

procedure that is becoming standard in the geophysical equipment industry. In any case the data rate that the GSC aeromagnetic system will generate precludes having the data output in the serial mode.

2. Interpretation of Magnetic Surveys

(a) Earth Physics Branch

MAGSAT

The Division of Geomagnetism is participating in the analysis and interpretation of magnetic field data from the MAGSAT satellite, as part of NASA's Resource Observation Program. The satellite was in orbit around the Earth from October 30, 1979 to June 11, 1980, at a maximum altitude of 561 km. We have selected MAGSAT data over Canada obtained during periods of low disturbance in the geomagnetic field, and are at present reducing these data to compensate for residual ionospheric and magnetospheric disturbances. Preliminary studies of the MAGSAT data show good correlations with the results of earlier studies of POGO satellite data over Canada and of upward-continued airborne vector magnetometer data. (R.L. Coles, G.V. Haines, G. Jansen van Beek, E. Dawson, J.K. Walker.)

(b) Université Laval

(i) M.K. Seguin et des étudiants de génie physique et génie géologique se sont appliqués à l'interprétation magnétique de divers blocs constituant le complexe ophiolitique des Appalaches du sud du Québec. La procédure utilisée a consisté à calculer les anomalies du modèle géologique envisagé par la méthode des intégrales de ligne et ensuite à comparer le profil calculé avec les valeurs du profil observé. La méthode est itérative et fait l'emploi d'un système graphique utilisant un écran cathodique et une photocopieuse. Nous avons amélioré les limites de positionnement ainsi que des dimensions des blocs individualisés en comparant les résultats magnétiques avec ceux obtenus par sismique réflexion dans certains cas.

(ii) M.K. Seguin avec l'aide de F. Terki et M. Kermoud a travaillé à l'élaboration d'un modèle à partir de données magnétiques terrestres prises sur et autour de la structure géologique soulevée du groupe de Maquereau dans la région de Port Daniel - Chandler, au sud de la péninsule de Gaspé. Les anomalies magnétiques se situent au pourtour de cette structure; ces anomalies sont toutefois discontinues.

(iii) M.K. Seguin et M.B. Mokrane effectuent une interprétation semi-quantitative à quantitative d'anomalies aéromagnétiques dans la zone des roches vertes de la région de Chibougamau. Il s'agit ici de développer des modèles magnétiques pour les provinces précambriennes et plus particulièrement pour les sous-provinces de Matagami - Chibougamau et Troilus - Frotet qui sont d'une grande importance économique dans la recherche de métaux de base.

(c) University of Manitoba

Magnetic anomaly interpretation over plutons in the Canadian Shield was carried out by D.H. Hall and T. Millar, Department of Earth Sciences. They have begun interpretation of MAGSAT data over the Canadian Shield in Manitoba and Saskatchewan.

(d) University of Windsor

Component magnetization studies on Archean Algoman-type banded iron formations (A-IF) from the Superior Province of northern Ontario are in progress. Some 1,500 to 2,000 specimens of A-IF and host rocks (HR) have been collected from each of the Sherman, Moose Mountain, Adams and Griffiths Mines. Their specific gravity for iron content, bulk and anisotropy of magnetic susceptibility, natural remanent magnetization, and demagnetization (viscous, alternating field, thermal, and chemical) have been measured. The relative contribution of each of these factors in the resulting aeromagnetic and ground magnetometer surveys has been analyzed and published for the Sherman and Moose Mountain Mines.

The effect of the anisotropy is so substantial that it significantly modifies the magnitude and shape of the anomaly to the extent that conventional analysis using only the orientation relative to the Earth's magnetic field, thickness, and grade (demagnetizing factor) will give false answers so that in Ontario where the Earth's field is near vertical: (1) all A-IF regardless of dip will appear to be vertical, and (2) only vertical A-IF deposits will appear to give significant anomalies. (D.T.A. Symons, M. Stupavsky, D. Walley, A. Quick, and I. Osmani.)

3. Magnetic Observations & Instruments

(a) Earth Physics Branch

Two stations in the Canadian Magnetic Observatory network, Meanook, Alberta and Resolute Bay, N.W.T., have been equipped with the new Automatic Magnetic Observatory System, AMOS MK III. These are the first installations in a program to replace the ten-year-old AMOS MK I at all stations in the network by 1983. The microcomputer-based AMOS MK III computes and stores mean hourly values and hourly ranges. These values, in addition to the one-minute data and self-checking diagnostic information, can be accessed by a remote terminal. Long term monitoring of equipment behaviour and stability is expected to continue throughout 1981.

A full description of the Canadian Magnetic Observatory Network and of the data available from this network is given in the Annual Report for Magnetic Observatories - 1978. In addition to the usual list of observatories, Alert rejoined the network in June, 1980. Other changes are given in the Aeronomy section of this bulletin. Copies of magnetograms and raw or edited digital data may be obtained at cost plus 100% handling charge from the Division of Geomagnetism, Earth Physics Branch, Ottawa, K1A 0Y3.

Twenty-seven-day forecasts of geomagnetic activity are issued every three weeks by the Ottawa Magnetic Observatory and are distributed on request. Beginning in 1979, short-term magnetic activity predictions up-dated twice a week and recorded in English and French were made available via telephone: (613) 824-5595. Starting on May 14, 1980, this service was continuously available throughout the year and is expected to be uninterrupted during 1981. In 1980 the Division began the publication of the Geomagnetic Bulletin, which contains articles relevant to the exploration industry. Details of other services available from the Division are listed in the Catalogue of Services for the Division of Geomagnetism.

The Observatory Unit of the Division of Geomagnetism acknowledges the long service of Mr. E.I. Loomer and wishes him well on his retirement which started in April, 1980.

Development of a second-generation, three component Ocean Bottom Magnetometer (OBM) was completed. The microcomputer-controlled OBMs will also measure two E-field components and record all five inputs for 36 days with a one-minute scan cycle. The instrument is held on the sea floor by an anchor which can be released at a pre-set time, or by a coded acoustic signal from the surface.

A low-power microcomputer system was developed for data acquisition of magnetic and electric field variations at remote locations and for on-site analysis of the data. The system scans the magneto-telluric inputs every 0.5 seconds, stores the data for an interval of 17 minutes and then does a Fast Fourier Transform on each component to produce the autopower and crosspower coefficients in four frequency bands. These are recorded on a cassette which has a 30-day capacity. The system draws 3.6 watts from a 12-volt battery. The cassettes are retrieved and read into another computer to compute the magneto-telluric tensors and transfer functions for monitoring the apparent resistivity in seismically active zones.

A fast-response, one component fluxgate magnetometer was developed and calibrated for the University of Saskatchewan's rocket-borne ejected spin probe. The probe is designed to spin and precess, thus providing vector information. First launch of the magnetometer-spin probe package is scheduled for March 1981, on the Falcons experiment.

The Schoensted Digital Spinner Magnetometers have been updated by replacing the PDP 11/05 minicomputer with an LSI 11 microcomputer. A similar LSI 11 system was interfaced to an analog Schoensted Spinner Magnetometer to achieve the same performance as the digital model has. With minor modifications the PDP 8 software runs in the LSI 11.

(b) University of Alberta - Instrumental development (D.I. Gough, D.K. Bingham, B. Telder, C.H. Bannister, V. Wynnchuk, A.O. Alabi)

Final testing of our 33 Gough-Reitzel magnetometers early in the year resulted in a few minor modifications. The 1980 field operations, reported in section 4, identified further minor problems in the new camera drive systems. These have been corrected. Dr. Alabi joined U. of A. for the summer, and his participation in the 1980 field operation was valuable. He also helped with data processing software, which he wrote during his Ph.D. programme. Dr. Alabi has eight new magnetometers in Nigeria and will shortly start field work there.

4. Electromagnetic Induction in the Earth

(a) Earth Physics Branch

(i) Lomonosov Ridge Expedition: Magnetovariational and magnetotelluric studies near the North Pole.

The analysis of the data recorded in the spring of 1979 under Project LOREX has continued. Transfer functions for the magnetic variations point away from the Ridge and have maximum amplitudes near 30 min periods. They can be well matched by a two-dimensional model which includes the sea water, the topography of the Ridge and a conducting layer in the lower crust and upper mantle. The model suggests that magnetotelluric data in the minor principal direction are least affected by the topography. One-dimensional inversion of these data using the programs of Oldenburg (1979) shows that the conductive sea water is of course well resolved. A conductive layer from mid-crustal to shallow upper mantle depths is indicated by the data. A second conductive layer at depths greater than 100 km is observed, but the long-period

results are insufficient to constrain it. The sea water of the deep ocean remains a formidable screen to surface magnetotelluric measurements aimed at crustal targets. (R.D. Kurtz and P.A. Camfield.)

(ii) Time dependence of magnetotelluric parameters

Magnetotelluric (MT) fields continue to be recorded at 60s intervals at three stations in the tectonically active region north-east of Quebec City as well as at a fourth station 130 km north of Quebec City. Work is in progress to correlate the interesting changes in MT parameters that have occurred in the past year at the first three stations with other geophysical measurements. Preliminary results indicate, among others, a correlation between polarization angle of the telluric fields, water depth in wells and tilting of the earth's surface.

In the latter part of the year a microcomputer was installed at the station near Les Eboulements. It has been programmed to sample the MT fields twice a second and to do preliminary processing of the data. This permits the examination of processes occurring at shallower depths in the crust and at the same time reduces the amount of data handling. As well, instrumentation was installed to monitor the DC potential on the telluric electrodes at the same station. (R.D. Kurtz and E.R. Niblett.)

(iii) Crustal electrical resistivity studies in the Grenville

Accurate determinations of depths and electrical resistivities of conducting structures in shield regions are often difficult because of the complex geology of the crust. Inversion of six decades of magnetotelluric (MT) data from a station with low skew and relatively small anisotropy in the Parc des Laurentides, Quebec, indicates the presence of good conductors at mid-crustal depths and at the base of the crust. In addition a conducting zone at approximately 120 km (top of the asthenosphere?) is well determined. Examination of data from six other MT stations as well as from previously published results indicate that a low resistivity zone at the base of the crust may extend over a considerable area in the Grenville. (R.D. Kurtz.)

(iv) Magnetometer array study, Saguenay-Laurentide area of Quebec

Pulsation events recorded in 1975 by this array of 26 variometers have been used to map an electrical boundary, traversed once previously by magnetotellurics, for 200 km along its strike. From MT, the structure is shallow and of limited depth extent, and involves a contrast in electrical conductivity of about one order of magnitude. It was detected by the array only in events polarized transverse to the boundary: E-polarization. Anomalous currents are hardly visible in substorm fields and their transfer functions; these fields are predominantly parallel to the structure: H-polarization. Inconsistent estimates of the inductive scale length $Z/\partial X/\partial x + \partial Y/\partial y$, computed from the smooth substorm fields, are evidently caused by source fields with strong vertical components and with horizontal scale lengths small relative to penetration depths. (P.A. Camfield.)

(v) Ocean Bottom Magnetometer Experiment

Three ocean bottom magnetometers were deployed west of southern Vancouver Island from July 23 to August 26 in 1980. The sites were at the top and bottom of the continental slope and 100 km

farther out, with respective water depths of 210, 2220 and 2700 meters. This is the first data set ever obtained across a continental slope. Initial inspection of the magnetograms shows that the majority of the electric current producing the geomagnetic coast effect flows in the deep ocean and not over the shelf. (L.K. Law.)

(vi) Geomagnetic Studies across Vancouver Island

To complement the ocean bottom magnetometer project, four magnetometers were operated in two set-ups along a line across southern Vancouver Island during the summer of 1980. The combined data sets will provide a good determination of the geomagnetic coast effect and lead to a better estimate of the conductivity structure in this area. (Jon M. DeLaurier, D.R. Auld.)

(vii) Geomagnetic Variation Anomaly in the Cascades

Previous geomagnetic studies in Washington State have been augmented by an additional twenty sites in the area north of Mt. Rainier and to the south of Mt. St. Helens. This cooperative project with the Geophysics Program at the University of Washington (J. Booker) extends the previously located anomaly near Mt. Rainier both to the north and south. (D.R. Auld, L.K. Law.)

- (b) University of Alberta - D.I. Gough, D.K. Bingham, M.R. Ingham, C.H. Bannister, V. Wynnchuk, B.Telder, J.H. de Beer (National Physical Research Laboratory, Pretoria, South Africa), A.O. Alabi, (University of Ife, Nigeria.)

(i) 1977 Array Study in South Africa - J.M. de Beer, D.I. Gough, J.S.V. van Zijl.

The Southern Cape Conductive Belt, reported last year, has been considered in relation to geology and tectonics of the region and to static magnetic and gravity anomalies. A model of its possible composition, mode of origin and tectonic implications has resulted.

- (ii) 1980 Array Studies in Western Canada - D.I. Gough, D.K. Bingham, M.R. Ingham, C.H. Bannister, A.O. Alabi, B. Telder, G. Ingham.

The field operations have been successfully completed for two array studies.

The 1980 large array employed 33 magnetometers distributed along four east-west lines from the Pacific coast to the great plains of Alberta. The area covered was about 4×10^5 km². The spacing of instruments along each line was about 150 km, and the corners of the array were at Edmonton, Prince Rupert, near Vancouver and at the Alberta-Saskatchewan border near the Canada-United States border. The objectives are two. The first is to detect and study gross differences in conductive structure between British Columbia (a region under which there is now active subduction of the Pacific lithosphere, and in which small continents may have been added to North America in Mesozoic time) and Alberta (part of the North American craton with a Phanerozoic sedimentary basin superimposed). The second objective is to locate possible geothermal energy sources for later study by means of small arrays.

Good magnetic variation data have been secured with recording efficiency 80 percent or better, for events covering a

period range from a few minutes to 24 hours, of various polarizations and from various types of magnetosphere/ionosphere source currents. This array borders upon the auroral zone of geomagnetic latitude in its northern limit. It is therefore important that it recorded some excellent daytime variation events as well as midnight substorms. The former should not present problems associated with an auroral zone electrojet very close to the array.

The array was operative over several days for which ocean-bottom magnetometers were recording in a program of the Pacific Geoscience Centre of the Department of Energy, Mines and Resources of the Government of Canada. We hope for a useful study of induction at the continental edge.

The 1980 small array employed 32 magnetometers covering about 4,000 km², at spacing 15 km. It was located over a known maximum in geothermal flux, in the Rocky Mountains foothills in an area near Edson and Hinton, Alberta. The question addressed by the project is whether there is an upper mantle-lower crust conductive structure due to partial melting, beneath the high temperature gradients observed in oil-wells in the area. We do not expect to detect the hot water in the upper crust, at the long periods (20s) recorded by our magnetometers. The films from the second array have received only a quick scan at the date of writing, but it is clear that the array recorded a good variety of events with efficiency about 90 percent. Minor faults in the new camera drives of a few instruments were detected in the first array study, and corrected before the second.

Editing and digitizing are in progress for data from both 1980 arrays.

Also, programs for the calculation of perturbation and induction arrows associated with three-dimensional models are being improved and variations in the arrows for anomalies at different depths are being investigated. The electromagnetic response of a subducting slab, in which the electrical conductivity is derived from the thermal regime obtained from the heat flow modelling work, is being studied. The effects of shear strain heating and upward movement of partial melt on the temperature regime, and consequently on the electromagnetic response, are being considered. Also, a study of the effect of a continental/oceanic interface in such models is underway.

(iii) 1981 Arrays

Two array studies will be attempted in the summer of 1981, probably both of the "small" variety. Localities will be selected later, with input from the 1980 arrays.

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. Numerical modelling and inverse methods are used as an aid to interpretation.

New instrumentation has been developed. The magnetic sensors have an extended band width, i.e. 125-.001 Hz and a new data acquisition system based on mini and micro computers is being used for the field operations.

Field studies on the Precambrian boundaries beneath the sediments, heat front detection in the heavy oil fields, and nuclear waste disposal sites, are in progress. The detection of geothermal anomalies continues to be of interest.

Numerical Modelling Studies (F.W. Jones, H.L. Lam, L.J. Pascoe)

The perturbation of uniform and nonuniform electro-magnetic fields by two-dimensional and three-dimensional electrical conductivity anomalies is being investigated by numerical techniques. The three-dimensional iterative electromagnetic induction program is being further developed and methods to improve its performance are being investigated.

(c) University of Manitoba

Deep electromagnetic crustal soundings, using 6 grounded conductors from two power lines in parallel running from Winnipeg to Lac du Bonnet, Manitoba were carried out using a square wave low frequency (0.5 Hz, 1 Hz and 5 Hz) source, providing up to 90 amp. current. Measurements were at about 250 stations on traverses perpendicular to the lines and up to 50 km in length, using magnetometers and magnetic field-sensitive coils. Inversion of the data are in progress. The use of 60 Hz signals for sounding using power lines was also experimented with.

Magnetometer monitoring of a 500 kv. power line as part of a study of solar induced currents was carried out. Correlation of these data with line current monitoring is in progress. The above two projects were carried out by D.H. Hall and R. Vohra, Department of Earth Sciences; L. Shafai, M. Tarnawecy and O. Aboul-Atta, Department of Electrical Engineering; and D. Woodford, Manitoba Hydro.

(d) University of Victoria - Geomagnetism Laboratory (H.W. Dosso, W. Nienaber, R. Chan, G. Heard, D. Herbert)

Electromagnetic Induction in the Earth

Laboratory analogue model measurements for a scaled Vancouver Island model were compared with magnetotelluric measurements from field stations, at various locations on Vancouver Island and the mainland, and with finite difference numerical calculations. These studies were carried out in collaboration with Dr. L.K. Law (Earth Physics Branch, Department of Energy, Mines and Resources, Victoria), Dr. F.W. Jones (University of Alberta, Edmonton), and Dr. V. Ramaswamy (Dehra Dun, India).

A model study of the British Isles region has been carried out in collaboration with Dr. V.R. Hutton (Edinburgh). The effect of the complex coastline and the surrounding shallow sea on induced electric and magnetic fields has been examined. The analogue model results are being compared with field station results available for the British Isles.

In collaboration with Dr. J.A. Wright (Memorial University), Dr. J.P. Greenhouse (University of Waterloo) and Dr. R.C. Bailey (Toronto), a laboratory analogue model of the eastern coast of Canada has been studied to delineate the effect of the coastline and bathymetry on the fields in the coastal regions. The model results are being used to produce contour plots of field components and ratios. The contour plots will provide reference values for the region, and differences between these reference values and field station values should be indicative of subsurface inhomogeneities and anomalies.

In collaboration with Dr. J.P. Lokken (Defence Research Establishment Pacific) a model study and a field station study of the coast effect in an Arctic bay is continuing. A field trip was carried out in April, 1980 to set up a line of field stations and obtain electric and magnetic field measurements over land and at the surface of the ocean using the ice as a platform.

An analogue model study of the Queen Charlotte Islands region, and a comparison of model results and field station results is underway in collaboration with Dr. L.K. Law (Earth Physics Branch, Department of Energy, Mines and Resources, Victoria). The model has been constructed, and the detailed measurements are being used to produce contour plots of field components for the region.

The problem of a conducting cylindrical ore body embedded in a poorly conducting host earth has been studied, both analytically and with the aid of an analogue model, in collaboration with Dr. S.O. Ogunade (University of IFE, Nigeria). Further problems of interest to geophysical exploration are underway.

(e) University of Toronto

Electromagnetic Induction

Measurements using a controlled source were conducted over the Meager Mountain geothermal area in British Columbia, to investigate possible correlations between the electrical conductivity and temperature, and over areas under consideration as disposal sites in Manitoba. Preliminary analysis of the Meager Mountain data suggests that the region is not highly conducting.

Mr. Enrique Gomez completed his Ph.D. research on the use of controlled-source sounding over reef structure in south-western Ontario.

Geomagnetic depth sounding, using natural magnetic field variations, was continued in the vicinity of the Michigan Basin. Observations made during previous seasons, in adjacent parts of Canada, had suggested that the basin appears as a large conductor. The 1980 observations, which included stations over the basin itself, confirmed the presence of conductors, but it now appears that these are more limited in extent than the basin; they may be related to sub-basin structures in the basement.

A new proposal for a controlled-source method of sounding the conductivity of the oceanic crust from ships was announced. The technique would employ a vertical cable, from ship to bottom as a transmitter, and sea-floor magnetometers as detectors.

5. Paleomagnetism, Rock Magnetism & Tectonomagnetism

(a) Earth Physics Branch

(i) Precambrian Program

A number of Precambrian rock units have been investigated during the last year. Some have been completed and the results have been published or are in press: a radiometric and paleomagnetic study of three rock units from the Belcher Islands, a study of multi-component magnetization of the Little Dal Group of the Mackenzie Mountains and an exhaustive study (contracted out) of the Sudbury Norite where seven distinct remanence phases have been recognized and separated. These studies illustrate the need for much detailed experimental work in order to uncover all the remanences contained in such old rocks. The first study provides

key poles since both the radiometric and paleomagnetic results were obtained from the same outcrops; the second shows that a wealth of information is contained in sedimentary rocks; and the third demonstrates that paleomagnetism can be a powerful tool for reconstructing the tectonic development of an area or complex with appreciable scientific and economical spin-off benefits.

Soon to be published is a study of the Tsezotene sills, another peg toward the construction of a polar path segment for the Mackenzie Mountains, with other units from the Little Dal Group, the Tsezotene Formation and the Katherine Formation presently under investigation. Work on the paleomagnetism of the Coronation Geosyncline is continuing with the investigation of the Cameron Group, the Hornby Bay and Port Radium Sills, and the Eastern Island Dyke Complex. Also under study are rocks from the Brock Inlier and dikes from the Mealy Mountain Complex.

(ii) Appalachians Program

Much effort is being devoted toward obtaining reliable data from Paleozoic rocks from the Appalachians and also from the Sahara for comparison. For the Sahara, results from 600 Ma old rocks of Mali have been published and results of a study of sediments from the Serie d'Abadla, Algeria have been submitted for publication. For Canada, results from Cambrian dikes and volcanics of the Buckingham area (Quebec) and from two sedimentary units of the Silurian Mascarene Group (New Brunswick) have also been submitted. In accord with the results obtained the previous year, the new results indicate that rapid apparent polar wander occurred during the Lower Paleozoic. In an attempt to delineate an APWP and to study the tectonic unfolding of the Appalachians, several other units are under investigation: Silurian redbeds of the Knoydart Formation, the Coldbrook Formation, Silurian redbeds from Antigonish, Cambrian diabases from the St. John area, the Moncton Group and the Chaleur Bay Group all from New Brunswick and Nova Scotia; in addition, the Maryston Group of the Burin Peninsula, Newfoundland, has been sampled. Paleomagnetic and rock magnetic results from a dike near Bellefeuille, Quebec will be published soon. A study of La Quinta Formation, Venezuela should be published in the coming year.

(iii) Arctic Islands Program

This program, commenced for comparison with the Appalachian results, is being intensified with the aid of the Polar Continental Shelf Project. A study of sediments from Prince of Wales Island is nearing completion and should be published within the next year. Sediments from Somerset Island are under investigation. Lower Devonian redbeds have been sampled on Cornwallis Island. The results should be most useful for establishing the integrity or non-integrity of North America in Paleozoic times.

(iv) Cordillera Program

Results from the Takla Group, the Hazelton Group, the Axelgold Intrusion and the Karmutzen Formation have been published. In order to test the idea that much of central and western British Columbia was formed a considerable distance further south than in its present position, samples were collected from the Lower Tertiary of southern BC and from the Jurassic (Bonanza Group) and the Cretaceous (Nanaimo Group) of Vancouver Island.

(v) Technical and Analytical Program

Much has been accomplished in instrument and computerization development to meet the need of a higher data output, both in quality and quantity.

The continuous high and low temperature magnetometer (CHALT) is being installed. The instrument will permit one to study and chart the magnetic characteristics of a specimen during treatment. This method has a marked advantage over the step-wise treatment for the detection of any chemical changes. Furthermore it permits one to determine the domain state of the magnetic minerals. Our SSM (Schonstedt) and JR 4 (Czech) magnetometers have been automated with LSI-11 microcomputers and our DSMs are being converted so that all measuring instruments (except the astatic) will have a standardized double output: a printed output containing all the information (12 measurements) and a cassette-recorded output of the intensity, declination and inclination with respect to specimen, horizontal and bedding, and the statistical parameter to assess the degree of uniformity (or non-uniformity) of within-specimen direction of magnetization. Transfer of data onto 9 track tape permits us to handle and analyse more efficiently by means of the computer and its peripherals the large amount of data obtained through the use of the several (including combination of) experimental and analytical techniques now available. A new 600 mT AF demagnetizer is now in operation.

(vi) Map and Interpretation Program

Updating of the paleomagnetic data is continuing. These data have been used to produce new paleocontinental maps for the Late Paleozoic (in press) and new maps for the Mesozoic and Cenozoic are now being developed. Several review and discussion papers of paleomagnetic data have been published or are in press: APWP segment obtained from the Coronation Geosyncline and its significance regarding relative motion between the Slave and Superior provinces, a correlation of Upper Proterozoic strata in the Cordillera, an analysis of the North American Precambrian data base, a review of the North American Lower Paleozoic data and the Eastern Seaboard problem and a review of the North American carboniferous results with its chronostratigraphic marker horizon.

(b) Ecole Polytechnique (E.J. Schwarz)

(i) Archeomagnetism

A set of potshards from Pointe du Buisson was investigated using Thellier's technique. The Results of 2 or 3 pieces from each of 7 shards show fair consistency although complicated above 400 to 500°C probably because of open air firing of the pots. The results were added to those obtained earlier for potshards from SW Ontario and suggest a general decrease in geomagnetic field intensity between 500 BC and 1000 AD (80% of present intensity) followed by an increase.

(ii) Massive sulphides, Noranda

Magnetic and electric properties of samples from the Corbet, Millenbach, and West MacDonald deposits in the Noranda area and the nearby Mattagami deposit were investigated to arrive at better criteria for the selection of exploration methods. The West MacDonald deposits show stable remanence (AF treatment) with a preliminary pole position of 40°W, 4°N which falls near the ~1700 Ma

portion of the apparent polar wander curve. Magnetic fabric is being evaluated. The experimental work was done at the Geological Survey of Canada.

(c) Geological Survey of Canada

(i) Circum-Ungava Belt

Stable remanence directions of Proterozoic red beds and volcanics in the Richmond Gulf area are comparable to those reported by Schmidt for the Eskimo volcanics of the Belcher Islands. Folding and relative dating of faulting suggest that this remanence is original (absolute dating of the rocks requires much further attention). The pole positions of these rocks cluster tightly near 0° Long., 40° S Lat. which is roughly 50° southeast of apparent polar wander paths as they are generally drawn.

The preliminary results for the Sutton Lake inlier and the La Grande 4 outlier indicate a time correlation between these Proterozoic rocks and the Flaherty volcanics in the Belcher Islands (which overlie the Eskimo volcanics).

Field work in 1980 centered on red beds in the Labrador trough and red beds in a number of Proterozoic outliers on the Superior Archean (e.g. Cambrian Lake, Sims Lake, Lac Gayot). Trough sediments sampled were the red beds near Chakonipau Lake and Lac Imbeault. Preliminary results are encouraging and it might be possible to arrive at time stratigraphic correlations which will also be of use in the uranium prospecting in the area.

(ii) Uplift from Remanent Magnetization

Two sampled profiles in different rock types through the contact zone with a 2150 Ma old dyke in Munro Township, Ontario, yield ambient host rock temperatures of $219 \pm 23^\circ\text{C}$ and $181 \pm 7^\circ\text{C}$. From these, the depth of burial of the present erosion surface is estimated at 6 1/2 km (+25%) 2150 Ma ago. A number of dyke (1250 Ma) contacts in the Sudbury area are being investigated. Preliminary results show fair consistency yielding a depth of about 10 km 1250 Ma ago. These results suggest a net subsidence of the area between 2150 Ma and 1250 Ma ago followed by a net uplift to the present time.

(iii) Baffin Island Dykes and Sediments

Good results were obtained which contain reversals showing the possibility of magnetostratigraphic correlations in the Borden sediments of Northwestern Baffin Island and possibly farther west (Boothia Arch). There are two sets of dykes and ages of the rocks are probably 700 - 800 Ma.

(d) University of Alberta

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

The Athapuscow Aulacogen and Kilohigok Basin are offshoots of the Coronation Geosyncline which contain several thousand metres of relatively unmetamorphosed sediments. Over the last decade, paleomagnetic investigations of several formations (totalling some 300 sampled stratigraphic horizons) have been undertaken to aid in understanding the tectonic evolution of this part of the Canadian Shield and to provide a possible means of correlation between the various elements of the Coronation Geosyncline. For the most part

the paleomagnetic poles obtained lie off the west coast of South America, and are best summarized in terms of a "Lower Coronation Pole" at 92°W, 14°S (N=8, K=23, A₉₅=12°).

One vexing problem that has persistently plagued paleomagnetic investigations of ancient sedimentary rocks is the widespread occurrence of multi-phase magnetization. In a recent study of the Akaitcho River Formation of the Great Slave Supergroup the underlying "primary" remanence was isolated by means of a statistical technique in which the relative magnitude of a later overprint was gradually incremented.

An attempt has been made to resolve the problem of the aberrant Stark and Tochatwi Formation poles by collecting new material from the Stark Formation.

A more direct experimental approach to multi-phase remanence is planned by means of chemical leaching in a newly-constructed ultra-high pressure device. Following successful initial pressure tests, certain modifications have been required to satisfy safety regulations. Progress on this project has therefore been temporarily halted, but it is hoped to have the apparatus fully operational early in 1981.

- (ii) Quaternary Geomagnetic Secular Variation (M.E. Evans, G.M. Ingham)

Olympia Interglacial sediments in British Columbia are being further investigated. The planned upward extension of sampling at the Bessette Creek site has now been carried out with a total of 211 horizons (727 samples) spanning some 16 metres stratigraphically now collected. The new collection is currently being processed and final results are not yet available. However, it seems clear that no trace of the Mono Lake Excursion of California is present. Rather one sees a continuation of "typical" secular variation swings in declination and inclination.

A new collection has been made of a possible "excursion" first reported by Westgate and Evans (1978) from a tephra-bearing sequence in southern Alberta. The original data were based on relatively widely-spaced samples (15 cm), whereas the new collection provides almost continuous coverage due to the use of a novel sampling technique developed by soil scientists. The method employs galvanized steel boxes (10cm x 50cm) which are pressed into the prepared vertical face of the outcrop (in this case a road-cut). Preliminary data look very promising and it seems likely that the new collection will provide a detailed record of the "excursion".

- (iii) Archeomagnetism (G.S. Hoyer, M.E. Evans)

Processing of samples from eleven archeological kilns collected in 1979 is nearing completion, and the results will allow the secular variation curve for southern Italy to be extended back to the 8th century B.C. The historic lava flows from Vesuvius have also been investigated and yield a secular variation curve which has the expected elliptical shape. To test the suggestion that mudflows may be very valuable archeomagnetic recorders, samples have recently been collected from a mudflow resulting from the 1980 eruption of Mt. St. Helens, and these are currently being processed.

It is possible to duplicate features of the secular variation curve by using a model in which the 1975 IGRF non-dipole field moves while the dipole field remains stationary. The model

predicts a mean deceleration rate of $0.004 \text{ deg. yr}^{-2}$ over the last two centuries. This is smaller by a factor of two than the currently observed deceleration rate, implying that the rate has been much smaller in the recent past.

(e) Dalhousie University, Department of Geology

(i) Iceland

The structure of the lower 2 km of a 3.6 km crustal section in eastern Iceland has been investigated using stable remanence declination as a guide to the azimuth of structural features. The section penetrates a linear dike swarm and shows increasing dip with depth directed toward the active volcanic zone of Iceland. Measurements of planar bedding features in volcanoclastics intercolated in the section, together with associated paleomagnetic data, are used to find lava accumulation rate when the area was part of the volcanically active zone. Rates vary from a few hundred metres/million years in the upper kilometer of the crustal section to $2 \frac{1}{2} \text{ km/my}$ at 4 km crustal depth. This model of lava accumulation rate and depth predicts almost exactly the observed 2.47 km thickness of sea floor spreading anomaly 5 age strata in the section (J. Hall, C. Walls, L. Hall).

(ii) Mid Atlantic Ridge

Magnetic measurements have been completed on subaerial basalts collected from a seamount 50 km west of Flores, Azores in 1979. Three basalt cores have inclinations averaging -73° and one has an inclination of $+10^\circ$ (dipole inclination $+59^\circ$). From thermomagnetic evidence magnetite is the major contributor to the NRM.

Magnetic measurements on basalts drilled on the MAR at $36^\circ 25' \text{N}$, $33^\circ 53' \text{W}$ are underway. Inclinations are everywhere shallow (stable -8° to -39°) compared to a site inclination of 54° . However the average intensity, $0.84 \times 10^{-2} \text{ emu/cc}$ at an inclination of -54° can successfully model the magnetic anomaly measured over the peak in the survey.

(iii) Bermuda

A drilling campaign in Summer 1980 managed by J. Peckenham (M.Sc. student) has yielded a second section of volcanics from Bermuda. The 100m volcanic section is located 3 km from our 800m 1972 drillhole. The new section contains pillow flows and diffuse intrusives of a geochemically highly evolved nature, perhaps related to the mid Tertiary dike swarm encountered in the 1972 drillhole. Extensive magnetic work on this new material is presently underway.

(iv) Nancy van Wagoner is continuing her study of the structure of upper oceanic layer 2 in the North Atlantic using a combination of segregation vesicles and paleomagnetic measurements. It has been possible to show that the glass lunes in segregation vesicles are gravity-controlled features. The extended measurements confirm the strong tectonic disruptions of the upper part of layer 2.

(f) Université Laval

Précambrien

(i) Archéen

Emile Gahé effectue actuellement une thèse de maîtrise sous la direction de M.K.-Seguin. Le sujet de cette thèse est: géophysique, géochimie et magnétostratigraphie des ceintures Archéennes: Matagami - Chibougamau et Troilus - Frotet. Il s'agit d'une étude comparative des deux ceintures de roches vertes et de quelques intrusifs granodioritiques, en utilisant la méthodologie suivante:

- (a) détermination des propriétés physiques (densité et susceptibilité ferromagnétique).
- (b) étude paléomagnétique et application des tests en laboratoire (par champ alternatif et thermique), de terrain (de dépliage et de cuisson).
- (c) analyses géochimiques.
- (d) quelques datations par méthode K/Ar.

Ces études visent les buts suivants:

- (a) élaboration de la magnétostratigraphie des séquences Archéennes.
- (b) test de l'existence de la tectonique globale à l'époque Archéenne.
- (c) impact économique de la minéralisation à la tectonique globale.

Ce sujet de thèse s'insère dans le cadre d'une recherche élargie permettant éventuellement d'établir une corrélation entre le Bouclier Canadien et celui de l'Afrique de l'Ouest. Quelques 124 échantillons orientés ont été prélevés à cette fin. Types de roches (nombre d'échantillons): gabbros (29), laves (31), granites (9), tufs (12), diabases (27), pyroxénites (4), aplites (3), dunités (3), agglomérat (2), diorites (3). Les travaux de terrain ont été effectués avec l'aide de trois équipes géologiques du Ministère de l'Énergie et des Ressources du Québec, soit celles de J.M. Charbonneau, A. Simard et M. Otis.

(ii) Aphebian

A preliminary study of the gabbro sills of the northern sector of the Labrador trough was undertaken in collaboration with the geological party of T. Clark from the Quebec Department of Energy and Natural Resources. Some five sites were sampled during the summer. Additional oriented samples will be collected next summer with the help of this same geological party.

(iii) Hadrynien

M.K.-Seguin et J. Brun ont échantillonné le gabbro de Portage situé à la frontière Québec - Ontario le long de la rivière Ottawa. Il s'agit de gabbros à méso et à microcristaux recoupés par quelques dykes de diabase. Ces gabbros recoupent les séries métasédimentaires (marbres) de la série de Grenville. Quelques 10

sites comprenant environ 53 échantillons orientés ont été recueillis. Des échantillons ont été pris dans les dykes et au contact des métasédiments pour effectuer le test de cuisson.

Paleozoic

(i) Cambrien (France)

Avec l'aide de M.F. Paris et M. Robardet de l'Institut de Géologie de l'Université de Rennes, M.K.-Seguin a débuté l'étude paléomagnétique d'une série pilote d'échantillons pris à l'intérieur de la Vendée (région de Les Essarts - La Châtaigneraie - Puy Hardy). Les formations représentées dans les synclinaux de cette région appartiennent au Cambrien (ou Cambro-Trémadoc) et à l'Ordovicien. Cette étude pilote permettra de savoir si les séries Cambro-Ordoviciennes du centre de l'Europe sont utilisables ou non pour fin paléomagnétique. Il appert que le métamorphisme est peu élevé et les intensités magnétiques sont facilement mesurables.

(ii) Middle Ordovician, Pennsylvania

With the help of L. Platt from Bryn Mawr College, Pennsylvania, M.K.-Seguin is undertaking a paleomagnetic pilot study of red cherts, basalts and related igneous lumps in the Martinsburg formation in Dauphin county, north of Lebanon. This formation is located in the allochthonous zone of the Appalachians. They are part of a klippe, but it is not known whether the sheets in the klippe are parts of a single body or separate bodies. Paleomagnetism may be useful to solve some of the structural problems of this region.

Laves Récentes et Tertiaires du Pacifique Central

Avec l'aide de H.G. Barszczus du Centre ORSTROM de Papeete, Tahiti, Polynésie française, M.K.-Seguin a effectué les travaux de recherche suivants sur des échantillons des Iles Moritini et du volcan sous-marin MacDonald:

- (a) propriétés magnétiques (susceptibilité, aimantation rémanente naturelle, aimantation rémanente isotherme, points de Curie, désaimantation thermique et température de blocage, désaimantation par champs alternatifs et spectres de coercivité).
- (b) Analyses chimiques (éléments majeurs et traces).
- (c) microsonde électronique.
- (d) études pétrographiques complètes en collaboration avec R. Laurent.
- (e) études minéralogiques et minéralogiques.
- (f) construction de diagrammes pour étude des conditions de différenciation.
- (g) évaluation de la fugacité d'oxygène.
- (h) géothermométrie.

Les roches principales sont des basaltes, hawaïtes, mugéarites, benmoréites et phonolites. L'évaluation des éléments traces et des propriétés magnétiques en fonction de la différenciation est utile pour la compréhension du mécanisme des panaches (mantle plumes) de cette région du Pacifique Central.

Une série d'autres échantillons provenant de Rapa, Tubuai et des Iles Marquises sera aussi étudiée.

Northern Appalachians

The paleomagnetic studies in this region will be divided into two parts: 1) Nova Scotia and Cape Breton Island, and 2) Newfoundland. These researches are concentrated on the Avalon zone. The idea is to test paleomagnetically the paleogeographic concepts proposed in the literature from Early Devonian to older geological times. The Avalon zone has been relatively ignored in terms of paleomagnetism in the past and in that respect this research is original.

(1) Nova Scotia

The research was done by M.K.-Seguin and K.V. Rao with the collaboration of E. Deutsch (Memorial). In the following lines, we will enumerate the formation studies, their lithology, their age and the number of sites sampled.

- (a) Fourchu formation, Lower Cambrian, consists of volcanics and volcanoclastics (12 sites), mafic dykes (7 sites), gabbros (8 sites); locations: southern part of Cape Breton.
- (b) Bourinot group, Middle Cambrian, volcanics (8 sites); sampled in collaboration with S. Barr (Acadia University, N.S.); location: south central Cape Breton.
- (c) Keppoch formation, Middle-Upper Cambrian, red beds and tuffs (8 sites); location: West of Antigonish.
- (d) Alaskite, Middle Cambrian, granite (9 sites); location: North of Antigonish on Northumberland Strait.
- (e) Eden pluton, Middle Cambrian, diorite (5 sites), location: central eastern Nova Scotia.
- (f) Bear Brook and Sunnybrae formations, Lower Silurian, basalts and tuffs (10 sites); location: Dunn Point, Northumberland Strait.
- (g) Torbrook formation, Early Devonian, shale, sandstone, iron formation (7 sites) cut by Middle Paleozoic gabbro sills (10 sites); location: Nictaux Falls, northwestern Nova Scotia.
- (h) Méguma (both Goldenville and Halifax formations), Upper Cambrian, Lower Ordovician, slates and greywackes (9 sites); location: Halifax and surroundings.
- (i) Central range granite, Early Carboniferous, granites and pegmatites (8 sites); location: Halifax and Nictaux Falls areas.
- (j) Fisset Brook formation, Late Devonian, sandstones and basalts (6 sites); location: south of Cheticamp, northern Cape Breton.

(2) Newfoundland

The field work was done by M.K.-Seguin and K.V. Rao. Except for a few sites collected on the Codroy group in western Newfoundland, all the paleomagnetic sampling was done on the Avalon zone, that is on the western (Colliers Bay) and eastern sides (Cape St. Francis) of the Avalon Peninsula. The largest part of the sampling was centered on the Harbour Main volcanics which include basaltic flows, rhyolitic sills, diabase dykes, ignimbrites and porphyrites. Some fifty sites were sampled on these different formations of Hadrynian age. An additional 9 sites were collected on the Cambrian Brigus shale.

(g) Memorial University of Newfoundland

(i) Precambrian and Paleozoic Paleomagnetism

A paleomagnetic study of the Gaskiers formation (C.G.B., 1977), a Late Precambrian tillite in the Conception group of the Avalon zone, eastern Newfoundland, has been completed as an M.Sc. thesis project by D. Morgan, together with E.R. Deutsch and G.S. Murthy. The study comprised 19 horizons of tillite in five areas separated by several km laterally, that were correlated by an uppermost red mudstone layer. Detailed AF and thermal demagnetization produced similar results yielding a negative fold test and a rather stable secondary magnetization, borne chiefly by magnetite. In most samples this appears to be the only component present, though a very stable, possibly primary component was found in some samples, especially of red mudstone. Thermal treatment of the prevalent component to 150°C resulted in a mean direction, $D = 171^\circ$, $I = +84^\circ$, $\alpha_{95} = 8^\circ$, for $N = 18$ sites. The corresponding pole position with respect to eastern Newfoundland is $35^\circ N$, $51^\circ W$ ($dp = dm = 16^\circ$). The magnetization was likely acquired as a viscous PTRM during the Acadian orogeny, in which case it represents an addition to several recently reported "anomalously" located poles of Silurian-Devonian age from sites in Atlantic Canada.

K.L. Buchan is examining the paleomagnetism of the Holyrood Granite of eastern Newfoundland, in order to investigate the evolution of the late Precambrian - early Paleozoic Iapetus Ocean.

E.R. Deutsch has completed a study of the mid-Ordovician (~460 Myr) Tramore volcanics, Co. Waterford, SE Ireland (C.G.B., 1977), which yielded stable remanence directions at 10 normal-polarity sites and 6 reversed sites. The mean direction corresponds to a north pole at $11^\circ S$, $162^\circ W$ ($dp, dm = 10^\circ, 13^\circ$; $N = 16$ sites). Confidence that the magnetization reflects a mid-Ordovician field direction is based on (1) a strongly positive fold test; (2) the presence of both polarities; and (3) indications that the remanence isolated after demagnetization is primary. The Tramore pole significantly diverges from most published mid- to late Ordovician paleomagnetic poles for the British Isles. The data support a 30° rotation of the British Isles relative to the geomagnetic field during the Ordovician.

J.P. Hodych and R.R. Patzold are completing a study of the paleomagnetism of folded Lower Paleozoic sills at Pt. Lance on the Avalon Peninsula of Newfoundland. These sills are thought to be of Upper Cambrian age (Rb-Sn dating is in progress) and were probably folded in the Devonian. A pre-folding remanence is uncovered by AF demagnetization. This remanence suggests that the latitudinal width of the Iapetus Ocean (Proto-Atlantic) was not great.

A paleomagnetic project on late Precambrian and Paleozoic rocks mainly of the Avalon zone in Cape Breton Island and mainland Nova Scotia was initiated by Professor M. Seguin and Mr. K.V. Rao of Laval University, jointly with E.R. Deutsch. Progress is reported in this chapter under "Laval University".

G.S. Murthy is continuing studies of magnetic properties of granites, diabase dikes and gabbros from the eastern margin of the Central Mobile Belt (Zone G) of Newfoundland.

Diabase dikes (3) have been dated as early Carboniferous and the location of their paleomagnetic pole does not support Kent and Opdyke's hypothesis of a systematic displacement of Appalachian poles from those of cratonic North America. The magnetization of some of the other granitic bodies and gabbros seems to be quite complex and experimental work is in progress to isolate a primary component of magnetization for these bodies.

(ii) Mesozoic and Cenozoic Paleomagnetism

The first Triassic rocks on the Island of Newfoundland were discovered by J.P. Hodych while investigating the cause of the Trans-Avalon aeromagnetic lineament. Paleomagnetism suggested that these rocks are Triassic in age. This was confirmed by K-Ar isochron dating by Dr. A. Hayatsu, University of Western Ontario.

Work is continuing on a large paleomagnetic project, supported by Aquitaine Oil Company of Canada, based on Mesozoic and Tertiary igneous rocks around the northwestern North Atlantic:

Graduate student J.N. Prasad and E.R. Deutsch have completed a study on 18 Mesozoic lamprophyre dikes they collected in 1979 with R.R. Patzold from a 70-km belt of exposures on Notre Dame Bay, central Newfoundland. AF and thermal demagnetization yielded comparable results, both giving well-grouped remanence directions close to the present Earth field direction for most of the dikes.

R.R. Patzold and E.R. Deutsch have studied the paleo-inclination of basalt core from three Mesozoic wells drilled on the Labrador shelf, finding both normal and reversed polarities, and paleolatitude values compatible with late Jurassic to early Cretaceous age.

E.R. Deutsch, R.R. Patzold and C. Brown collected 190 basalt samples from 36 early Tertiary flows and 2 dikes on Durban and Padloping Islands west of Cape Dyer, Baffin Island. This is for paleomagnetic comparison with results from basalts of similar age in west Greenland which may provide evidence on the timing and geometry of opening of Baffin Bay.

(iii) Magnetic Remanence, Stability and Domain Structure

E.R. Deutsch, R.R. Patzold and Dr. C. Radhakrishnamurty (Tata Institute of Fundamental Research, Bombay) measured magnetic hysteresis and initial susceptibility at different temperature on coarse, synthetic titanomagnetite samples of composition $\text{Fe}_{2.4}\text{Ti}_{0.6}\text{O}_4$ ("TM60"), with and without minor cation substitution typical in Layer 2 basalts. The results closely resemble the "Type 1" behaviour found in some oceanic basalts containing coarse TM60.

Work is continuing on isolating the source of stable remanent magnetism in rocks (G.S. Murthy).

K.L. Buchan and J.P. Hodych are investigating the possibility of anisotropy of acquisition of magnetic remanence in some red beds. In particular, the Clinton formation of New York and Alabama and the Wabana formation of Newfoundland are being studied.

(h) University of Toronto, Department of Physics

(i) Fine Particle Rock Magnetism (D.J. Dunlop, K. Argyle)

Ken Argyle has begun preparing sized magnetite samples with the object of filling a long-standing data gap in the 0.25-2 μ m particle size range. Because of the difficulty of synthesizing magnetites of this size by either chemical precipitation or grinding, well-sized hematites are being reduced to magnetite at moderate temperatures. The TRM and hysteresis properties of these samples should permit a critical test of conflicting models of pseudo-single domain behaviour (wall and surface moments, nucleation, etc.).

(ii) Chemical Remanent Magnetization (CRM) (C.J. Hale, M.E. Bailey, D.J. Dunlop)

CRM is believed to be quite common in nature, but its identification is usually by indirect methods. These methods involve knowledge of the formation conditions of a rock and subsequent metamorphic events which chemically alter the magnetic minerals. We are particularly interested in developing a laboratory test to identify CRM and in comparing its magnetic behaviour with that of the less complex TRM. These experiments are of direct interest in interpreting our paleointensity studies on oceanic basalts (which have acquired CRM's during low-temperature oxidation on the sea-floor) and on the very old (3.3 GA.) Komati Formation ultramafic lavas from the eastern Transvaal (which may have acquired a CRM during serpentinization).

We are inducing laboratory CRM's in cation-deficient titanomagnetites. The following experiments are underway.

- (a) Field dependence on CRM. CRM is induced in a series of low-fields (3 oe) to test for a linear (or other) field dependence of the CRM intensity.
- (b) Directional Studies. CRM is induced in samples which have been previously demagnetized and samples with intact NRM's in both zero and known laboratory fields. Early results show that the CRM direction and intensity is controlled by both the internal field (resulting from the NRM) and the external laboratory field (for $H = 0.5$ oe).
- (c) Coercivity and blocking temperature spectra of CRM and a TRM are being compared in the same sample. It is hoped that this will lead to a method of distinguishing between CRM and TRM in the same mineral.
- (d) Paleointensity experiments. Samples which almost certainly contain a CRM have given apparently reliable paleointensity results with the Thellier method. We are further testing this observation through Thellier experiments on our laboratory induced CRM's.

(iii) Experimental Calibration of Blocking Temperatures (C.J. Hale)

The time (or cooling-rate) dependence of blocking temperature is being tested in experiments using synthetic 0.2 m 'Mapico' magnetite. Five samples of varying concentration are exposed to the earth's field for two to four weeks at a constant temperature of 400°C. The resulting viscous remanence (vrm) is then thermally demagnetized, in steps, to 700°C.

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

Measurement of the various natural remanent magnetization components exhibited by mafic rocks from the Abitibi Subprovince yields evidence, not only for primary magnetizations, but also for episodes of thermal magnetic overprinting at approximately 2.6 Ga, 2.1 Ga and 1.8 Ga. The sample suite, taken in the Kirland Lake - Matheson, Ontario area, contains specimens from throughout the Archean greenstone volcanic-plutonic pile (2.7 Ga), as well as from the Matachewan (2.6 Ga) and Abitibi (2.1 Ga) diabase dike swarms which intrude the pile.

The steeply dipping Archean basalts yield a uniform, high coercivity-blocking temperature magnetic direction which corresponds to the "cleaned" direction of intruding Archean gabbros. Geological suggestions that the volcanics and plutonics are consanguinous and that the structure in the volcanics developed during deposition, imply that this direction may be primary. The aggregate paleopole falls at 29°S, 4°E. The Matachewan and Abitibi dike paleopoles of 45°N, 70°E and 41°N, 230°E, respectively, agree with the results of several previous studies.

(v) Paleomagnetism of the Archean Poobah Lake Alkaline Complex, Quetico Subprovince (D.J. Dunlop).

In many samples, normal and reversed magnetization are superimposed, the normal magnetizations being systematically steeper than the reversed ones and resembling Shelley Lake granite results. Implied are either magnetization during very slow cooling or partial overprinting of nrm, as well as polarity epochs of long duration around 2.7-2.6 Ga. NRM vectors systematically swing from normal to reversed orientations on AF demagnetization, but from reversed to normal on thermal demagnetization. On a thermal overprinting model, the normal magnetization should be older. Positions of the paleopoles on Track 6, however, predict the opposite sequence: reversed nrm's older (~2.7 Ga), normal nrm's (pole similar to that of the 2.6 Ga Shelley Lake granite) younger (~2.6 Ga).

(vi) Wabigoon Gabbro and WNW-trending Dikes, Wabigoon Subprovince (D.J. Dunlop)

The Wabigoon gabbro occasionally exhibits an nrm component like the 2.7-2.6 Ga nrm of the Poobah Lake complex, but more prominent is another magnetization with declination about 65° and inclination about -5°, whose paleopole is consistent with a magnetization age of either ~2.8 Ga or 1.2 Ga (Mackenzie igneous episode). This magnetization is found in 32 of our 60 samples, greatly improving resolution of the direction (as of 1979, the average was based on 11 samples).

(vii) Tudor Gabbro, Grenville Province (D.J. Dunlop, M. Zeller)

A small sampling of the Tudor gabbro was undertaken because of the exciting discovery by Dr. A.K. Baksi (paper in preparation) from $^{40}\text{Ar}/^{39}\text{Ar}$ step heating mineral ages that the body cooled through $\sim 550^\circ\text{C}$ about 1.1 Ga, and thereafter cooled very slowly, reaching $\sim 300^\circ\text{C}$ about 0.9 Ga and $\sim 200^\circ\text{C}$ about 0.7 Ga.

Magnetic results on 10 samples show single-component nrm's with well-marked blocking temperatures in $525\text{--}550^\circ\text{C}$ or $550\text{--}575^\circ\text{C}$ ranges. Thus the disconstant Tudor gabbro pole is probably about 1.1 Ga old and, together with Cordova gabbro C and Thanet gabbro B poles, may define a novel, pre-Grenvillian orogeny APWP track for Grenvillia. Further sampling will be carried out in the spring of 1981.

(viii) Grenville Traverse" Across the Grenville Front, Southern and Grenville Provinces (D.J. Dunlop, M.O. McWilliams, Stanford University)

Measurement and analysis is complete for the 1979 collection of 39 samples from 1 late Hadrynian dike south of the Front and 9 Nipissing diabase sites in 2 parallel traverses north of the Front, all on or near Highway 11. Thermal cleaning was done at Toronto and AF cleaning at Stanford.

(ix) Archean Paleofield Intensity (C.J. Hale)

Twelve selected Matachewan and Abitibi diabase samples from the Abitibi Basin were run in full double-heating Thellier experiments. The Matachewan samples gave generally good results, yielding paleo-intensities ranging from 1 to 3 times the present field strength, in accord with previous work by Carmichael, Schwarz and Symons. Abitibi samples were generally unsuccessful.

Paleointensities for five type-locality samples of the Komati Formation of the South African shield (supplied by Dr. M. DeWit of the Bernard Price Institute, Johannesburg) gave generally lower-than-present field strengths. The $^{40}\text{Ar}/^{30}\text{Ar}$ age of the same samples, determined by Dr. Derek York and colleagues at Toronto, is 3.3 Ga, making these the oldest terrestrial paleofield intensities ever determined. Because of these encouraging results, a sampling expedition to Barberton Mountain area of the Transvaal was undertaken in the fall of 1980. Eventually comparison paleointensity determinations will be made with Archean komatiitic lavas exposed near Matheson, Ontario.

(i) University of Western Ontario - Department of Geophysics

(i) Paleomagnetism of Devonian Age Dikes in the Glen Coe region, Scotland (C.M. Carmichael)

An extensive collection of samples of dikes and dike contacts was made, (to add to a previous small collection), in the Glen Coe area and also along Loch Leven and south of Oban. These are interpreted as being late Devonian in age and it is hoped that they will provide additional information about the pole positions of this period for which the existing data are quite scattered.

(ii) Paleomagnetism of sediments from Lake Erie (C.M. Carmichael)

A nine meter core from Lake Erie, obtained by the Canada Centre for Inland Waters during Oct, 1979, was subsampled and

measured in the Department of Geophysics, Edinburgh, during a period of sabbatical leave in 1980. Further, coring was carried out during November, 1980 in Lake Erie and these data will be combined in an attempt to improve on the record of the field over the past 10,000 years.

- (iii) Paleomagnetism of sediments from Lake Ontario (C.M. Carmichael and J.S. Mothersill (Lakehead Univeristy)

A joint project has been undertaken to measure the magnetization of cores from Lake Erie. These were collected by the Canada Centre for Inland Waters in October, 1980. Duplicate cores were taken in the basins at the eastern and western ends of the lake to be measured independently at Western and at the University of Edinburgh by Dr. Mothersill. In the western basin it was found that the sediment was in excess of 18 meters in thickness.

- (iv) Paleomagnetism of Mesozoic and Cenozoic Rocks from the Andes and Caribbean Region (H.C. Palmer, A. Hayatsu & W.D. MacDonald, SUNY, Binghamton)

Two papers reporting on paleomagnetic and K-Ar results from the Andes have been published this year (Palmer, Hayatsu & MacDonald, 1980). The most important conclusion from these studies is that some rock units from the Andean-Caribbean orogenic belt appear to have undergone rotations about local vertical axes.

While attending the 9th Caribbean Geological Congress this past summer, Palmer and MacDonald collected samples from the Tertiary of Hispaniola. This project has as its objective the unravelling of tectonic effects caused by the interaction between the Pacific and Atlantic plates on the Caribbean plate.

- (v) Late Precambrian Rocks of the Lake Superior Region (H.C. Palmer and H.E. Halls, University of Toronto)

Two papers involving the nature of the spatial and temporal distribution of secondary remanences in Keweenaw rocks are in press. The first of these two papers concerns the remanence re-setting in lava pebbles contained in conglomerates from the Keweenaw succession at Mamainse Point, Ontario and from the Copper Harbor Formation of Michigan. The conglomerate data indicate an early (pre-tilting) remagnetization event, the intensity of which varies along strike on the Keweenaw Peninsula. The spatial variation of this remagnetization event is studied in the second paper where the paleomagnetic data are derived from lava flows within the Copper Harbor Formation.

The third study in the Keweenaw trilogy was begun this past summer. The oldest of the Keweenaw asymmetric reversals (which generates the ascending limb of the Logan paleomagnetic loop) is currently based on the data of Books (1972) from the South Range Traps.

- (vi) Paleomagnetism of Hadrynian Lavas, Sills and Reynolds Point Formation Shales, Victoria Island (H.C. Palmer, W.R.A. Baragar, G.S.C.)

A combination of AF and thermal demagnetization techniques has revealed a R-N-R reversal stratigraphy within the 800 m-thick Natkusiak basalt succession. The poles derived from these results are typical of the Franklin Magnetic Interval.

- (vii) Paleomagnetic and Age Studies of the Fury and Hecla Formation, Baffin Island (H.C. Palmer and S.L. White)

A collection of redbeds and interbedded lavas was made during the summer of 1979 from the Fury and Hecla Formation with the logistical help of F.W. Chandler of the Geological Survey of Canada. The laboratory work has been completed on approximately half the collection. The data so far in hand support the correlation of the lavas within the sequence with those of the Nauyat Formation on the Borden Peninsula.

- (viii) Paleomagnetism of the Tindir Supergroup, Alaska (H.C. Palmer and S.L. White)

Material for this study was obtained during the summer of 1979 in a cooperative project with C. Allison of the University of Alaska. Although all the material collected has been prepared for laboratory measurement no data have yet been obtained.

- (ix) Proterozoic Dikes of Northern Ontario (H.C. Palmer, F.O. Aibangbee and K.D. Card, G.S.C.)

Subsequent to our work on the Sudbury dikes of the Grenville Front region (Palmer et al., 1977) an additional 46 sites have been examined and oriented samples have been collected at these sites. Although some of these sites are in the type areas of the Matachewan and Abitibi dike swarms, the purpose of this study is to ascertain the lateral extent of these igneous episodes with the aim of assessing the number and relative magnitude of periods of crustal extension in this part of the Canadian shield.

- (x) Magnetostratigraphy of Late Wisconsin sediments, Southern Ontario (H.C. Palmer and B.E. Broster)

An apparent episode of high amplitude secular variation as recorded in a short profile of Lake Maumee silts exposed near Iona, Ontario encouraged us to document this "excursion" of the geomagnetic field by an examination of a number of other profiles within the Maumee silts and in the underlying Port Stanley Till.

- (j) University of Windsor

- (i) (D.T.A. Symons, M. Stupavsky, D. Walley, A. Quick and I. Osmani)

Paleomagnetic studies of 1,500 to 2,000 Algoman-type banded iron formations (A-IF) and host rocks (HR) have been completed and published on each of the Sherman and Moose Mountain Mines in the Superior Province of Ontario. Both deposits retain internal pre-folding primary (~ 2.8 Ga) and secondary (Algoman metamorphic, ~ 2.5 Ga) remanence poles after AF, thermal and chemical demagnetization which agree after tilt correction between the deposits. Similar studies are in progress on the Adams and Griffith deposits.

- (ii) D.T.A. Symons, M. Stupavsky and S. Dey

Paleomagnetic studies are nearing completion on the Memesagemesing and North Caribou Lake norite stocks in the Grenville Province just south of the Grenville Front near Sudbury. Using data from ~ 600 specimens from ~ 55 sites, the analysis includes bulk magnetic susceptibility, anisotropy of magnetic susceptibility, natural remanence, demagnetization (AF, thermal and chemical), host

rock contact, dike contact (depth of burial), and polished section studies.

(iii) D.T.A. Symons

Paleomagnetic studies are underway on rock units from the Insular Belt (West Coast diorite, Karmutean dike contacts) and Interior Plateau (Cache Creek and Hazelton volcanics) to examine aspects of the early geotectonic evolution of the Cordillera.

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

Paleomagnetic studies have been completed on two 45 km long profiles extending north from the Grenville Front involving 100 sites in Huronian Gowganda sediments and Nipissing diabase. The basic conclusion is that the remanence imprint of the Grenville Orogeny extends only ~2 km into the Cobalt sedimentary plate.

(v) M. Stupavsky

Paleomagnetic studies have begun on specimens from ~54 sites of "Nipissing equivalents" in the Grenville Province close to the Grenville Front in northern Ontario. These rocks could retain some primary Nipissing components and/or very old Grenville metamorphic components if the thermochron model is valid.

(vi) M. Stupavsky and D.T.A. Symons

A single step screening method to select only reliable remanence data for paleomagnetic interpretation from a set of highly dispersed remanence vectors has been developed. The method involves plotting all the remanent vectors on two stereonet, up directions on one plot, down directions on the second plot, smoothing and contouring the two plots to locate any anomalies.

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III (B) AERONOMY AND SPACE PHYSICS

Compiled by: D. Venkatesan

1. Introduction

GOVERNMENT OF CANADA

2. Environment Canada
3. Energy, Mines and Resources
4. National Research Council, Herzberg Institute of Astrophysics
5. Department of Communications

UNIVERSITIES

6. McMaster University
7. University of Alberta
8. University of British Columbia
9. University of Calgary
10. University of Victoria
11. University of Western Ontario
12. York University

1. Introduction

This report is compiled on behalf of the Division of Aeronomy and Space Physics (DASP)/Canadian Association of Physicists (CAP). DASP has since its formation effectively contributed to the cohesion and coordinated efforts of the Community of aeronomers and space physicists in Canada. The annual meeting (usually held in February of each year) was not held in 1980, since a significant fraction of the members were involved in the field operation of the "Pulsating Aurora Campaign", in Saskatchewan, during a two week period in January and February. The meeting in 1981 will be held as usual in February (19 and 20, at Saskatoon).

The material for this report was provided by various research groups belonging to Government Institutions and Universities in Canada, to Mr. L. Erwin, Canada Centre for Space Science (CCSS)/National Research Council (NRC), Ottawa.

The primary purpose of this report is to present an overview of the activities of the various institutions listed above. Thus no bibliography has been included. Furthermore, only three institutions have supplied references, thus the inclusion of the material would not be representative of all the activity.

My thanks are due to Messrs. L. Erwin and N. Hussain, Secretary CCSS/NRC, Ottawa, for all the help in gathering and organizing the material.

GOVERNMENT OF CANADA

2. Environment Canada

- (a) Atmospheric Environment Service (A.E.S.),
Atmospheric Research Directorate (A.R.D.)

The Atmospheric Environment Service operates a network of receiving stations for the United States operational meteorological satellites, NOAA and GEOS. These stations serve to provide satellite imagery for both weather and sea-ice forecasting. The imagery is distributed over dedicated land-lines to photofacsimile receivers in seventeen forecast offices across the country. In addition to direct read-out imagery, additional meteorological satellite imagery is also received from the United States photofacsimile network and LANDSAT imagery is received from Canada Centre for Remote Sensing. During 1980, negotiations were completed for a joint Danish/Canadian read-out station at

Sondre-Stromfjord in Greenland. This station will provide the AES with the high Arctic coverage which was curtailed by the lower orbit of the latest series of polar orbiting meteorological satellites.

The Research and Development (R & D) programs in satellite meteorology of A.E.S. are directed toward increasing the utilization of satellite data in those applications which are not satisfied by available processed data via the Global Telecommunication System. The present R & D activities include the following:

(a) The combination of geostationary meteorological satellite data with ground-based weather radar data to provide automated short-term forecasts of precipitation and severe weather. This program, which began with the basic research being contracted out to the Stormy Weather Group of McGill University, has now almost reached the prototype system stage. The prototype which is being built by Goodwood Data Systems will be delivered early in 1981.

(b) A program to develop useful tools for forecasting severe weather, based on the available sounding measurements from the polar orbiting meteorological satellites. During 1980 the first version of the computer-based system was developed and the initial tests started. The service had also embarked on a COPI project in this area in conjunction with MacDonald Dettwiler and Associates, a major Canadian supplier of systems for processing meteorological satellite data.

(c) A system for precision re-mapping of HRPT data has been developed as a first step toward machine-assisted image analysis in support of sea-ice monitoring and forecasting. The precision re-mapping was required to permit both temporal and multispectral analysis procedures to be used in interpretation of the HRPT data. This system will also be used as part of a Great Lakes temperature monitoring system which uses radiosonde data of temperature and humidity to derive atmospheric corrections to the radiation temperatures as well as to provide re-mapped imagery for snow cover mapping as part of the St. John River basin project.

(d) The Service has carried out evaluations of SEASAT data and potential applications to ice and weather forecasting. One of these involved an investigation of the low data rate sensor data applications to regional forecasting off the Pacific/Atlantic coasts and in the Arctic. The results obtained thus far indicate that the scatterometer-derived wind measurements can be assimilated readily into the subjective surface analysis over ocean areas and substantially improve the reliability of the analysis and subsequent forecasts.

(e) A sophisticated data analysis and display system is under development to provide weather forecasters with interactive access to a combination of weather satellite imagery and conventional meteorological analysis. This system, part of the Ocean Station Papa replacement program, will be installed in the Vancouver weather office late in 1981.

Finally, it is relevant to point out that the R & D programs are not limited to satellite-borne measurements. A system to process data relayed by the polar orbiting satellite from data collection platforms has been developed. This system not only converts the satellite signals into standard meteorological code, but also provides the position of the platform. The major purpose of the system is to support the use of drifting buoys in the Pacific, Arctic and Atlantic oceans to provide data on sea-surface temperature, air-temperature and pressure.

(b) Atmospheric Environment Service-Ice Branch

As part of the radar satellite program, AES has assumed the responsibility for the ice mission requirement study, the ice information centre mission concept study, and is participating at all management levels of the radar satellite program. An ice project office is being set up in Ottawa in conjunction with Ice Forecasting Central and Ice Climatology to carry out this program.

Activity with the NIMBUS-7 Scanning Multi-frequency Microwave Radiometer (SMMR) team is continuing. The current effort is devoted to the validation of SMMR sea-ice signatures for different types of ice in the Beaufort Sea.

(c) TIROS "N" Station at Sondre-Stromfjord, Greenland

A TIROS "N" satellite ground station is being installed at Sondre-Stromfjord in Greenland as a joint Canadian-Danish project.

The station will be able to handle a Data Collection System (DCS) and to receive and process Advanced Very High Resolution Radiometer (AVHRR) signals from the satellite. The DCS data is separated from the main data stream and sent to the user. The AVHRR data is fed to the Weather Information Processing System (WIPS) where the five (visual and I.R.) channels of information are separated and recorded, then a selected channel is fed to the image recorder. The product is an image of photographic quality that can be re-transmitted by telephone photo-facsimile to Canada or other users.

It is planned that the station will start operation in January, 1981.

(d) A.E.S. Experimental Studies

UVB monitoring with the Smithsonian instrument was initiated. AES scientists participated in WMO international pyrhelimeter comparison V. The AES mark II sunphotometer has been placed in commercial production with Sonotek, Ltd. Continuous pyrgeometer monitoring of long wave fluxes has been in progress. The phase two multipyranometer data set for solar energy statistics has been extended. The AES automatic suntracker prototype has been tested and three production prototypes have been constructed.

The new Mark II ozone spectrophotometer has been tested and is ready for commercial production. Interference of sulphur dioxide on Dobson total ozone measurements has been discovered and evaluated. Sulphur dioxide is monitored on a routine basis from Toronto with the Brewer spectrophotometer. Total column amounts of 4 to 5 milliatmosphere-cm are typical. Surface based measurements of total atmospheric ozone on a daily basis are continuing at the five stations; Churchill, Edmonton, Goose-Bay, Resolute and Toronto. The vertical ozone profile up to 30 km is measured by balloon sounding with ECC sondes each Wednesday.

Theoretical simulations of constituent data sets from STRATOPROBE flights indicate that hydroxyl densities in the 15 to 30 km region are low. The consequences of the low hydroxyl densities on the depletion of ozone by fluorocarbons have been evaluated with a scenario model. The predicted depletion of ozone at current usage rates is less than 10%, with 1980 depletions less than 1%. To test the low hydroxyl density theory a collaborative experiment with NASA-Goddard scientists was conducted in October, at the NSBF in Texas.

3. Energy, Mines and Resources (E.M.R.) - Earth Physics Branch (E.P.B.)

(a) Magnetic Stations and Observatories

The Observatory Unit of the Division of Geomagnetism increased the magnetic observatory network from 11 observatories to 12. The observatories are: Alert, Resolute Bay, Cambridge Bay, Baker Lake, Mould Bay, Fort Churchill, Great Whale River, Yellowknife, Meanook, St. John's, Ottawa and Victoria. Alert rejoined the observatory network in June, 1980. With the closing of the Churchill line of I.M.S. variation stations, the operation of Whiteshell station became by agreement the responsibility of the University of Manitoba. Responsibility for instrumentation and data editing remained with the Observatory Unit. Whiteshell was moved to Glenlea (Southern outskirts of Winnipeg) in October, 1980.

With the completion of the data collection phase of the I.M.S. and MAGSAT projects, the I.M.S. variation stations Rankin Inlet, Eskimo Point, Back, Island Lake, Thompson, and Fort Severn were closed on 30 June, 1980, and Pelly Bay in March, 1980.

A variation station was established in October 1980 at Igloolik (69.4°N, 278.2°E). Only digital data measuring the variations in D, H and Z every ten seconds will be available. The station will facilitate studies of the magnetospheric cleft region, establish a magnetic diurnal pattern for the magnetic repeat-station program and anticipate the placement there of geomagnetic instrumentation for the O.P.E.N. project.

As E.P.B.'s contribution to the F.A.L.C.O.N. project, the Division of Geomagnetism has provided four data-loggers to the Space Research Facilities Branch (SRFB/NRC). These equipments will provide 10-second digital data of variations in the geomagnetic field at the four stations: Churchill, Gillam, Eskimo Point and Rankin Inlet. The binary tapes will be transcribed and made available by the Observatory Unit of the Division of Geomagnetism.

A full description (excluding the recent updates mentioned here) of the Canadian Magnetic Observatory Network and the Churchill line of I.M.S. magnetic variation stations is contained in the 1978 annual report for magnetic observatories. The geographic and geomagnetic locations of these stations, their recording intervals and types of recorders and the approximate cost and availability of these data are listed in a catalogue which is available on request.

(b) Convection and Auroral Arc Currents

A detailed analysis of the ground-based and rocket-borne observations across two auroral arcs on 15 January, 1972 indicated a complex system of currents. The Hall and Pedersen currents along the rocket path were determined from Ohm's law using the rocket-borne energetic particle, plasma and electric field observations and compared with those determined independently from magnetic field measurements. A very active region poleward of the arcs consisted of both eastward and westward convection currents and may have been a remnant of an earlier sub-storm. The ionospheric currents in the arcs were eastward. These current systems could not be identified from nearby ground-based magnetic observations. Field-aligned currents were calculated to flow inward on the poleward edge of the active region and outward above the arcs. These currents exceeded the critical current of the topside ionosphere and they also appeared to be the boundaries of cells which contained the active and the auroral arc regions.

(c) Thermospheric Heating and Magnetic Disturbances

Preliminary studies indicate that Joule heating in the auroral zone during disturbed conditions can be several hundred gigawatts. Heating in the cleft and polar-cap can at times be comparable. Such heating can significantly perturb upper atmospheric circulation. Parameters are being developed to characterize the heating from magnetic observations, with a view to investigating the changes in the upper atmosphere during magnetic storms.

(d) Undisturbed Magnetic Baselines

A method for determining the undisturbed or quiet night-time baseline for magnetic observatories has been developed and applied. These baselines have been used as a reference level for determining magnetic perturbations for the analysis of external currents and could be used for correcting nearby magnetic surveys for temporal changes. From values determined over an extended period of time, they have also been used for estimating the secular variations at a number of Canadian observatories.

(e) Solar and Lunar Variations

The following investigations have been carried out by J.C. Gupta: A study of Sq and L using 21 years of hourly geomagnetic data from Nurmijarvi, Finland. Sq is found to be 15-20 times larger than L at this station. The L-current system is much stronger in summer than in winter. Results also indicate that the poleward part of the Sq and L-current systems are considerably modified during the course of the year, probably by the auroral electrojet.

A study of the IGY/C geomagnetic hourly-data from Ebro, Spain clearly indicates a poleward shift of the Sq-focus during the noon hours. Also, the spectra of the H-component reveal a significant influence of gravitational tidal forces on the magnetic field.

Time-series of hourly geomagnetic data from 12 observatories, mostly in North America, have been analyzed for solar and lunar variations using the Chapman-Miller method. The average length of the data is 36 years with the longest and shortest being 71 and 19 years respectively. The harmonic coefficients have been published in the Internal Geomagnetic Series of the Earth Physics Branch.

(f) Magnetic Pulsations

The following investigations have been carried out by J.C. Gupta; An analysis of the Pi2 data from Ottawa, Meanook, Baker Lake and Resolute Bay for the interval May 15, 1970 to May 14, 1971 reveals various morphological features; these have been discussed in detail. A 27-day recurrence tendency in the period of Pi2's is recognized. Also a lunar tidal influence on the occurrence of Pi2 is suspected from the observed strong occurrences of Pi2's at all four locations at a certain lunar phase.

4. National Research Council - Herzberg Institute of Astrophysics

(a) Planetary Sciences Section

(i) Auroral Spectra and Photometry

The analysis of the 1.0 to 1.6 μm auroral spectrum obtained with the BOHEM Michelson system has been completed. As a result of acquiring a good auroral spectrum throughout this region, an

improved electronic transition moment function for the N_2^+ Meinel system was obtained.

The 12-inch $H\beta$ photometer at Pakenham, Ontario was operated throughout all new-moon periods once again. Quite a number of small proton precipitation events were observed, but no very large events were detected. It is anticipated that routine observations will be terminated in the spring of 1981.

A multichannel monochromatic imager was assembled to observe the auroral morphology during Waterhole I. It consisted of a TV ISIT camera, rotating filter wheel, bore-sighted single channel photometer, microprocessor control system, digital recorder, TV monitors, Quantex image processor and video recorders. No conclusive results have been obtained so far, but further analysis is proceeding. A more comprehensive set of imaging observations for Waterhole II is being considered.

Instrumentation is being developed in preparation for the Auroral Modelling Campaign, and initial observations will be conducted from Churchill and Gillam in February 1981. The system is designed to measure the auroral spectrum as a function of height, by employing two TV cameras to determine the height and a third camera to measure the spectrum. Real-time calculation of intersecting look angles will make it possible to follow rapidly moving aurora so that the chances of obtaining spectra of Type-B aurora are improved.

(ii) IMS Project

Final calibrations for the photometric observations have been derived, and final plots for the selected sub-storms are being prepared. Using magnetogram data, onset time and an onset longitude for each of these sub-storms have been determined. In addition, for a more exclusive sub-storm set, the time histories of the sub-storm longitude sector and the latitude profile of the current system are being studied. Comparisons will be made between the morphological features of the luminosity profiles and those of the current systems.

(iii) Pulsating Aurora Campaign

Observations were made with zenith photometers and meridian scanning photometers from Saskatoon, La Ronge, and Rabbit Lake in January and February 1980. Latitude profiles of electron and proton aurora were obtained along the chain of stations. Pulsations were monitored in the zenith, and characteristic periods and times of occurrence were derived in collaboration with Duncan (Saskatoon). Observations of numerous forbidden emissions in the zenith at La Ronge yielded good results, and software development has been initiated to analyze the results.

(iv) Rocket Photometry

N_2^+1PG and N_2^+1NG emission data obtained from the flight of the AAF-NVB-06 electron gun payload show that beam plasma discharge (BPD) was observed during the downleg. These data are presently being studied to discover the altitude below which a transition from single particle behaviour to BPD occurs and how that altitude varies with beam current and energy.

Photometers were flown on two rockets (ADD-VA-50/52) during the pulsating aurora campaign. Good data were obtained from rocket ADD-VA-52 while a partial failure occurred on rocket ADD-VA-50.

Six photometer channels were flown on the Ionospheric Depletion (Waterhole) payload (AAF-NVB-07). The wavelengths measured are tabulated below.

<u>Species</u>	<u>v' v''</u>	<u>$\lambda_{\mu m}$</u>
OH	(0,0)	306.4
N ₂ ⁺ 1N	(0,0)	391.4
OI	---	557.7
OI	---	630.0
N ₂ 1P	(4,2)	750.5
O ₂ Atm	(0,0)	762.0

These data are partially analyzed and a preliminary time history of the water cloud in 306.4 has been produced.

A photometer is now being readied for a reflight of the Waterhole experiment in January 1982.

(v) Auroral Photometry

Extensive data were obtained during the pulsating aurora campaign and although auroral activity was unusually low, a total of some 40 hours of good pulsating aurora data were obtained. Two aspects are being investigated; statistical analysis of pulsations as a function of time and latitude, and the relation between the pulsating and the proton auroras.

Successful data were obtained as part of project Waterhole. Although the rocket trajectory was at a very different azimuth from that predicted, the meridian scanner combined with the all-sky camera data strongly suggest that simultaneous with the release, a general change in morphology of the arc and a reduction of the overall intensity of the arc were observed.

(vi) Pc 5 Pulsations

Work by ourselves and others over the years on pulsating radio aurora has been very fruitfully extended by the STARE group recently, which has led to a useful improvement of Pc 5 pulsation theory. Our own work has also led to the development of a new approach to pulsation theory (PSS, 28, 713 and 727) based on a lumped circuit description of nature. The kernel of that development is being transformed into a distributed non-uniform transmission line description of the resonance. To date we have defined and built a model of a longitudinally-limited toroidal mode which yields both the transient and steady-state solutions and which contains an excitation circuit. We have seen that the resonance amplitude vs geomagnetic latitude is an analog of the amplitude vs frequency response of a resonance. Thus a phase shift of approximately 180° in the steady-state response as one varies the latitude of observation through the resonance must be seen as predicted by the work of the STARE group. Work is continuing in the development of our model.

(vii) Probe Measurements in Auroral Plasmas

Plasma probes were flown successfully on five Black Brant rockets in the past year. These experiments were multiple-probe instruments designed for the measurement of electron density and temperature in natural auroral events and in active perturbation

experiments. One of the probes in each instrument was expressly designed for the detection of suprathermal electron fluxes which are associated with particular events. All of the instruments incorporated a microprocessor for real-time control of the electronics to optimize the sensors and to process the signals.

The probe experiments on the AAF-NVB-06 mother and daughter sections measured the local plasma and vehicle effects induced by an electron gun carried on the mother vehicle. On the AAF-NVB-07 (Waterhole I) flight, the plasma probes directly measured the ionization hole created by the explosion and the subsequent plasma behavior until the payload passed beyond the region of perturbation. During the pulsating aurora campaign in Saskatchewan in January/February 1980, the plasma probes were flown on rockets ADD-VA-50 and ADD-VA-52. Good data were obtained on electron density variations, supra-thermal electrons, and electron temperatures.

An unfortunate engine malfunction in the Ariane rocket launch from French Guiana in May 1980 resulted in the loss of the Firewheel experiment which included a plasma probe on the Canada sub-satellite.

(viii) Radio Aurora

With the initiation of the new Canadian space science program, scientific planning and preliminary conceptual design of a high power, high-resolution dual-Doppler radar system has begun. It has been demonstrated by radio auroral research that the drift velocities of auroral scattering irregularities are related to the ionospheric electric fields that drive them. The present objective is to build a Canadian Bistatic Auroral Radar System (BARS) which will generate continuously large-area maps of electric fields in the auroral zone. Used in conjunction with co-located photometer, imaging, and magnetic arrays of instruments, this instrument will participate with several satellites in NASA's Origin of Plasmas in the Earth's Neighborhood (OPEN) program for the study of the ionosphere and magnetosphere.

A study of radio aurora observed at high aspect angles (8° - 12°) from Thompson has shown that the scatter amplitude is related to the magnitude of the geomagnetic disturbance in the same way as observed at low aspect angle. Previous work showed that the relationship of afternoon diffuse radio aurora to field-aligned currents remained unaltered in going from low to high aspect angles. Thus the scatter we observe at high aspect angle has features in common with observations of other workers at low aspect angle, with the distinct exception of the aspect sensitivity. We observe a much less aspect-sensitive scatter than others do.

(ix) Spacelab - WISP/HF

The investigators' team for the Waves in Space Plasmas/HF facility has been progressing with experiment planning and development of design concepts and specifications. The WISP/HF facility is a high power radio wave injection and reception instrument to be flown on Spacelabs during the Space Shuttle program. The particular interests of the Planetary Sciences Section are in the use of this facility as an orbiting radar system for the study of auroral E-region backscatter and of F-region plasma instability structure. The latter can be simultaneously measured with plasma probes and other instruments on the Spacelab.

(x) Meteor Research

Radar Observations

The meteor radars at the Springhill Meteor Observatory were operated for a few days during each of the major meteor showers. Such data accumulated over a long period of time (now > 20 years) determine the cross-section of a meteor stream and the distribution of particles around the stream. Differences in these distributions as a function of the size of the meteoroids are important in assessing the past and continuing evolution of meteor showers.

Photometric Observations

A sensitive (light) intensified TV camera was used to record meteors during the August Perseid shower. Cloud-cover prevented observations on the night of shower maximum. Since the return of the parent comet (1862 III P/Swift-Tuttle, period 120 year) is expected some time within the next three years, the shower is being monitored for possible increased activity associated with the comet.

Spectroscopy

Efficient photometric techniques for the analysis of meteor spectra secured with TV cameras are of particular importance as the electronic image-intensified observing systems give us a large quantity of data. Work is continuing on the photometric reduction of over 1000 meteor spectra secured with TV equipment at the Springhill Meteor Observatory and at the Mt. Hopkins observing station of the Smithsonian Astrophysical Observatory. This program is being carried out in cooperation with the Space Sciences Laboratory of the NASA Marshall Space Flight Center in Huntsville, Alabama. In particular, a search is being made for possible variations in the chemical composition of the meteoroids from different comets.

Meteorite Recovery

Among the bright meteors observed by the MORP camera network in 1979 and 1980, two probably had associated meteorite falls. A small meteorite is indicated for an event near New Sarepta, Alberta during January 1979 and a substantial meteorite is believed to have fallen near Fork Lake, Alberta during September 1980. In cooperation with the staff of the University of Alberta, educational campaigns and limited field searches have been conducted in both areas. The camera network also recorded the re-entry of the launching rocket of Cosmos 1220 on November 4, 1980. The terminal phases of luminous flight were near North Battleford, Saskatchewan.

A photometric and dynamic study of the separate trails and fragments of the Innisfree meteorite has yielded values for the luminous efficiency in the velocity range from 3 to 10 km s⁻¹. The decrease of meteoroid velocity is more important than loss of mass by ablation in this range and efficiencies in the range 10⁻² to 10⁻⁴ are typical.

The reduction of fireball data for various statistical studies is proceeding with 70 fireball trajectories reduced by December 1980.

Infrasound

A careful study has been made of the Saskatoon infrasound records during the periods when bright meteors were recorded on the MORP camera network. No correspondences have been found. It is believed that the propagation of meteor-generated infrasound is more highly directional than supposed and hence the likelihood of optimum orientation of a meteorite path with respect to the observing station is small. A final assessment of the data is being made.

Interplanetary Dust

New infrared observations of thermal emission from the zodiacal light were combined with currently available optical observations to estimate the geometric albedo of the dust particles at 0.04 and their Bond albedo at 0.09, both uncertain by about a factor of two. The particles are nearly black in the thermal infrared and grey in the optical spectral region.

Miscellaneous

Staff members of the meteor group played a large part in the organization of the International Astronomical Union (IAU) Symposium No. 90, Solid Particles in the Solar System, in August 1979. This work has culminated in the publication of the Proceedings edited by two of our staff. The volume contains eleven papers which survey particular areas of the overall subject as well as numerous contributed papers which provide more detail on specific problems.

The history of research in the field of meteor spectroscopy during the period from 1864 to the present, has been surveyed with emphasis on the work of A.S. Herschel as the pioneer in this field.

(xi) Comets and Planetary Rings

The mode of origin and the size distribution of the particles in a meteor shower can be studied shortly after their release from the parent comet if a sunward pointing "anti-tail" can be studied photometrically. Observations at the time of the Earth's passage through the comet's orbit plane are most effective but for short-period comets very few anti-tails have been detected. An attempt was made in May 1980 to obtain such observations with the 3.6 m Canada-France-Hawaii telescope for a faint periodic comet, P/Honda/MrkosPajdusakova. No anti-tail is evident in the photographs but image processing techniques might still provide some evidence. Accurate positions were derived from the photos since it appears that only two sets of observations were secured at this apparition.

Laplace's model of a ring of elliptical cross-section and no internal strength has been extended and shown to fit the circular Rings of Uranus. Elliptical rings of varying width may be fitted by a modified version of the model of Goldreich and Tremaine.

(b) Space Physics Section

(i) Auroral Plasma Studies

Studies of the electrodynamics of auroral arcs, using rocket-borne passive observation as well as active perturbation or tracer techniques, have been pursued on several fronts.

In the area of passive observations, an energetic ion mass spectrometer with a large geometric factor (one to two orders of magnitude more sensitive than those currently in use) has been developed for observations in auroral events and is capable of detecting the expected minor ion constituents in auroral precipitation (i.e., O^{6+} , He^{3+} , Fe^{+} , etc.). This device will be flown in January 1981 into an auroral form and is expected to yield new information on the auroral ion source regions as well as ion energization, transport and loss processes.

A program ("Falcons") to study the relationship between auroral arc, field-aligned currents, local electric fields and energetic particle precipitation is planned for March 1981. Two rockets will be launched nearly simultaneously on the same flight azimuth, one to an apogee of 350 km and the other to 800 km over a chain of ground-based magnetometers and into an auroral arc. The ground magnetometers and imaging and photometric scanning systems will provide information on the temporal stability and spatial structure of the auroral forms and currents during the rocket flight. The rockets will be instrumented with thermal and energetic charged particle detectors and vector electric and magnetic field sensors.

It is anticipated that these observations will result in a determination of the magnitude and location of the auroral current systems and will therefore provide a test of the relevance of current driven instabilities to the auroral electron acceleration mechanism.

A campaign to study the morphology and source mechanisms of pulsating aurora, which involved a number of ground-based optical observations (TV imaging, scanning photometers, etc.) along with coordinated sounding rocket launchings, was carried out during January and February 1980. Results from this campaign will appear in a special issue of the Canadian Journal of Physics in 1981.

The second campaign, planned for December, 1981, will study the "cleft" or dayside aurora from sites near Cape Parry, N.W.T. Two high altitude rockets will be instrumented to measure energetic ion and electron precipitation, ionospheric ion drift velocities, and electric and magnetic fields.

Both rocket campaigns will be supported by extensive ground-based observations.

In the area of active experimentation, a joint NASA/NOAA/NRCC program to study the interaction of electron beams with the ionospheric plasmas and to use the beam as a magnetospheric probe is continuing. A programmable electron gun operating in the 1 to 10 keV energy range and capable of producing beam currents from 1 to 100 ma was developed and has been flown in two sounding rockets from Churchill Research Range. Data from these flights are presently under study. Preliminary analysis indicated that a beam-plasma instability, identified in pre-flight tests in the large Johnson Space Center vacuum tank also occurred in space.

Some data from probes ejected from the main rocket carrying the electron gun indicate that at times prompt echoes from electron gun firings, perhaps returned by field-aligned electric fields, were detected. This use of the beam to probe for E_{\parallel} was one of the main objectives of the program.

A third rocket in this series was recently operated in the JSC vacuum tank to simulate flight conditions. Vehicle charging effects and beam-plasma instabilities were studied in this controlled environment. The rocket was subsequently launched from CRR in December 1979. Beam-plasma instability effects similar to those observed previously were once again observed in space and are currently under investigation.

The last of these series of electron gun flights is now scheduled for December 1981.

Project "Waterhole", launched in April 1980, was a perturbation experiment aimed at disturbing the ionosphere-magnetosphere coupling mechanism. A large quantity (100 kg) of chemically reactive vapours were released into the F-region above an auroral arc which had the net effect of temporarily reducing the local electron density by several orders of magnitude over a diameter of 10 km and by at least an order of magnitude over a 50 km diameter.

Simultaneous with the release the energetic electron precipitation through the "hole" was cut off and the morphology of the auroral arc, 10 km equatorward of the "hole", changed markedly. These perturbations in the electron precipitation pattern lasted for approximately three minutes whereupon the aurora recovered to its pre-release condition. These results clearly show the crucial role played by the ionospheric plasma in the acceleration mechanism for auroral electron.

A follow-on program "Waterhole II" is now scheduled for January 1982.

(ii) Magnetospheric Studies

The "Firewheel" satellite was the main payload for the ARIANE development flight LO2 which was launched on May 23, 1980. The experiment involved Barium and Lithium releases in the nightside magnetosphere at 9.5 and 7 earth radius (R_E) respectively. The scientific objectives were: i) to study the plasma processes controlling the formation and decay of a magnetic cavity, ii) to study the momentum exchange with the ambient plasma and the magnetospheric perturbation thereby generated, iii) to observe modifications of the trapped energetic particles by self-generated whistler and ion-cyclotron waves, and iv) to trace the acceleration and redistribution of the injected ions in the inner magnetosphere.

Unfortunately, a malfunction occurred in the first stage motor and the satellite failed to achieve orbit. A follow-on to this program is currently under consideration.

The Space Physics group is collaborating with a group at Lockheed Missiles and Space Corp. on an energetic ion mass-spectrometer for the high altitude Dynamics Explorer spacecraft. Along with analysing the results from this instrument, NRC has the prime responsibility for executing coordinated ground-based and sounding rocket observations. Some chemical seeding and tracer experiments will also be coordinated with DE spacecraft passes. This spacecraft is now scheduled for launching in June 1981.

The joint National Research Council - Lockheed Missiles and Space Corporation program to develop a large energetic ion mass-spectrometer for Spacelab has now entered the project

development stage. The sensitivity and mass resolution of this instrument will greatly exceed any previously flown instruments since it is only the large weight carrying capability of the Shuttle that makes this instrument feasible for space experiments. This instrument is being developed for flights in the years 1984-1986.

NRCC scientists form one of 34 investigator teams selected by NASA to analyse data from the MAGSAT satellite which was launched on October 30, 1979 and re-entered the earth's atmosphere on June 11, 1980. The NRCC investigation will concentrate on disturbance fields of external origin caused by ionospheric/ magnetospheric current systems with emphasis on high latitude current distributions. The preliminary test data which have been received to date have been used to model auroral electrojet and Birkeland current distributions in the afternoon sector for individual satellite passes. The 7 1/2-month data base will be used to construct models of average global current systems as a function of local magnetic time, solar illumination, geomagnetic latitude, interplanetary magnetic field and geomagnetic disturbance indices.

A study of electrical conductivity in the high latitude ionosphere, using average precipitating fluxes of electrons obtained from the ISIS-2 satellite, has been completed by D.D. Wallis and E.E. Budzinski (J. Geophys. Res., 1980). Two-dimensional distributions of height-integrated Pedersen and Hall conductivities have been computed for latitudes poleward of 60° invariant. The models include ionization due to solar photons as well as galactic EUV and other background sources. The conductivity distribution shows considerable spatial gradients as well as a substantial modulation due to longitudinal variation in the magnitude of the geomagnetic field. The results are expected to be useful in numerical modelling of MAGSAT data.

(iii) Theoretical Studies

Theoretical analyses of the ionosphere and magnetosphere were aimed mainly at describing and explaining the global structure of the magnetic field aligned currents (FACs) observed on the polar orbiting satellites.

It has been shown that the FACs in a geomagnetically quiet plasma sheet plasma are always generated if the fieldlines have a non-zero curvature and if the current density perpendicular to the fieldlines has a non-zero component in the direction of the principal normal to the fieldlines. The FACs observed above the auroral zone ionosphere are a natural consequence of the magnetic field structure in the plasma sheet which is enforced by a mechanical action of the solar wind.

The global structure of the FACs in the ionosphere is related to the high-altitude enhancement of the total density of the ionospheric gas in the auroral oval. The density enhancement is due to Joule and precipitation heating at lower ionospheric levels which results in a mechanical imbalance and upward motion of the atmospheric mass in the auroral zone ionosphere. The ionospheric closure currents connecting the FACs flow inside the auroral oval mainly in the eastward or westward directions; they flow in the meridional planes only in the immediate vicinity of the peak of the density enhancement.

Future theoretical studies will analyse the relation between the topology of the magnetospheric current system and energization of the plasma.

(iv) Cosmic Ray Studies

The NRC Space Physics group continued to operate cosmic ray monitor stations at Deep River, Alert, Inuvik, Goose Bay and Ottawa. Preliminary neutron monitor data summaries and graphs are submitted monthly for publication in Solar-Geophysical Data (NOAA). Final data reports are issued for general distribution yearly.

The operation of the near-horizontal muon detector array is being continued in order to improve statistics and to observe the dependence of the sidereal anisotropy on the solar magnetic cycle. Although the magnetic polarity of the solar north and south polar regions has apparently reversed during the past 10-15 months, no significant change in the sidereal anisotropy has yet been observed in any of the scan directions.

A study of the long-term variation of the solar diurnal anisotropy has been completed using Ottawa and Deep River neutron and muon monitor data which has been accumulated for the past 24 years. We have confirmed the existence of pronounced 11 and 22-year variations in the anisotropy first reported by Forbush for the period 1935-1957 on the basis of ionization chamber observations.

The launch date for the Solar Polar Mission has been postponed from 1983 to 1985. This has resulted in an eight-month slippage in the engineering model test and delivery schedule.

5. Department of Communications

(a) Communications Research Centre

(i) The ISIS Satellite Program

The general objective of the ISIS program is to conduct comprehensive studies of the ionosphere. It involves making measurements over a range of heights and latitudes sufficient to determine conditions in the ionosphere and to achieve a full understanding of this region out to the magnetosphere boundary.

It is presently planned to terminate the ISIS data-taking program in March 1981.

The following satellites are still operational:

ISIS I

Under the terms of special studies conceived by the ISIS experimenters' group, ISIS I gathers data at a typical rate of 1.5 hours per day. All 10 experiments, with the exception of the ion mass spectrometer and soft particle spectrometer, are performing as planned. The Soft Particle Spectrometer records data for 10 seconds to 3 minutes after turn on. As well, by using the onboard clock and programmer and tape recorder, much useful data were obtained on the ionosphere over previously unexplored regions of the globe until clock and tape recorder failure occurred during February 1970. One battery is presently out of use but this presents no problems.

Swept Frequency Sounder - This topside ionospheric sounding experiment covers a frequency range of 0.1 to 20.0 MHz.

Fixed Frequency Sounder - The fixed frequency sounder operates on six crystal controlled frequencies within the range of the swept frequency sounder - 0.250, 0.480, 1.000, 1.950, 4.000 and 9.303 MHz.

Mixed Mode Sounder - This experiment uses a fixed transmitting frequency of 0.833 MHz simultaneous with a receiver which sweeps through the complete frequency range of the topside sounder.

VLF Receiver/Swept Frequency Exciter - This is basically a low-frequency receiver covering the frequency range of 50 Hz to 30 kHz, which permits experimental studies of the upper ionosphere and exosphere and the complex interaction between the ionized media and low energy particle streams.

Energetic Particle Detector - This package contains two groups of detectors capable of identifying electrons and protons and measuring their angular distributions and energy spectra over the energy range for electrons from 8 keV to greater than 770 keV and for protons from 50 keV to 20 MeV.

Soft Particle Spectrometer - This spectrometer was designed to measure the energy spectrum, angular anisotropy and spatial and temporal variations of both positive and negative particles in the energy range of 10 eV to 10 keV.

Cylindrical Electrostatic Probe - This is an instrument which measures electron temperature and density. The purpose of this experiment is to extend the satellite measurements into the period of solar maximum.

Spherical Electrostatic Analyzer - The objective of this experiment is the measurement of spatial and temporal variations in the concentration and energy distribution of charged particles in the altitude region of the satellite.

136/137 MHz Beacon - This instrument consists of two 100 mw transmitters operating at 136.410 and 137.950 MHz (the former being the tracking beacon) and measuring the scintillation in the total electron content of the ionosphere between the satellite and the ground station.

Cosmic Noise - This experiment measures the galactic radio noise levels above the F-layer ionization maximum.

ISIS II

Most experiments and spacecraft systems are working well. The exceptions are the tape recorder (failed late 1971), soft-particle spectrometer (deteriorated 1973-1974) spacecraft clock (1974) and most of the channels on the energetic particle detector (1976-78). The cylindrical electrostatic probe became intermittent in April 1978. The low-mass channel of the Ion Mass Spectrometer experienced a decrease in sensitivity in 1974 and failed in 1979. Data are acquired at a typical rate of 1.5 hours per day, all for special studies.

Swept Frequency Sounder - The objective of the experiment is to determine the electron number density at and below the satellite down to the peak of the F-layer and to study the size and location of irregularities in the ionosphere.

Fixed Frequency Sounder - The fixed frequency sounder is designed to provide observation of small-scale irregularities which are too limited in extent to be easily investigated by the swept frequency sounder and to complement the swept frequency sounder, particularly where

rapid horizontal variations occur. The fixed frequencies are 0.120, 0.480, 1.000, 1.950, 4.000 and 9.303 MHz.

VLF Experiment - This experiment is basically a low frequency receiver covering the frequency range from .05 kHz to 30 kHz. Because of the large range in amplitude of naturally occurring VLF signals, the receiver has a dynamic range of about 80 dB, which is achieved by the use of an AGC system.

Cosmic Noise - This experiment measures the so-called cosmic noise, or more specifically the natural background radio noise level, with a sweep frequency receiver orbiting substantially above the F-layer ionization maximum. In general the background noise level is determined by galactic noise, (but with contributions from plasma processes) and information on its variation with direction in the galaxy and with observing frequency is desired.

Retarding Potential Analyzer - The objective is to measure the positive ion density, composition, and temperature in the vicinity of the spacecraft. The secondary objective is to measure the thermal electron density and temperature, and the flux of suprathermal electrons.

Soft Particle Spectrometer - This experiment is an improved version of the experiment flown on ISIS I which provided good detailed information on the fluxes and energy spectra. The energy resolution has been improved to provide better data on the spectral line width and shape. Particles are detected in two separate beams to provide a check on the variability of the flux on a short time scale.

Energetic Particle Detector - The experiment is designed to measure intensity, angular distributions and energy spectra of electrons and protons. An energy range of 1 keV to 1 MeV is covered for electrons. There are two energy ranges for protons, auroral energies 2-20 keV and "solar flare" energies 0.9 - 30 MeV.

Beacon Experiment - The beacon experiment aboard ISIS is an improved version of the equipment aboard ISIS I. The purpose of the experiment is to detect and measure inhomogeneities in the ionosphere between the spacecraft and a number of ground stations.

Cylindrical Electrostatic Probe - The main objective of the experiment is to extend through the 11-year solar cycle the study of the global behavior of electron temperatures and density that was begun with the combined data from the Alouette II and Explorer XXXI and with data from the ISIS I satellite.

Red Line Photometer - The purpose of this experiment is to map the global distribution in the intensity of 6300 Å line emission from the D level of atomic oxygen.

Auroral Scanner Photometer - The scanning photometer is designed to map the distribution of auroral emissions at 5577 Å and 3914 Å over the portion of the dark earth visible to the spacecraft.

The operational program of both ISIS satellites continues to be coordinated by the ISIS Working Group, as provided for in the 1964 Memorandum of Understanding. During the past five years the program has ceased to concentrate on routine data acquisition and analysis, and instead has been devoted almost exclusively to special studies. Such studies may be defined on the basis of some special feature identified in the data, on some more fundamental basis for which satellite data specific for the purpose are acquired, or on the basis of some other, non-ISIS, observations or experiment where collaboration with some ISIS experiment is desired. Coordination of these special studies is provided by the ISIS Experimenters' Committee.

Satellite Support Services

The ISIS program provides support services in the form of one telemetry station, a data processing centre and a data centre at Ottawa. The Ottawa station is the central station for the ISIS satellites. The Department of Communications closed the Resolute Bay station in August 1979.

(ii) Radio Studies of the Ionosphere

Research

Radio Wave heating of the ionosphere generates ionization irregularities. It is generally believed that this is caused by self-focusing of the heating wave. Using published data, D.B. Muldrew indicates that this is probably not the case; small irregularities act much like antennas, absorbing energy from the wave and thus causing them to grow.

Low latitude irregularities (spread-F and ducts) have a strong longitudinal dependence due to the displacement of the magnetic and geographic poles. It has been found, by D.B. Muldrew, that this dependence applies up to about 50° dip latitude. However, the data do not cover the region between $\pm 10^\circ$ dip latitude near the F-layer peak.

An F-region model of the ionosphere over North America has been developed using Alouette I data. Magnetic tapes and the final report by J.C. Galdwin will soon be available. F-layer frequencies, layer thickness and spread-F can be estimated as a function of sunspot number, local time, magnetic activity, latitude and longitude.

Spacelab Plans

In the spring of 1980, the National Research Council of Canada (NRCC) proposed to supply the medium and high-frequency system in the Wave-In-Space-Plasmas instrument complement (WISP/HP) for Spacelab missions to be undertaken by the National Aeronautics and Space Administration (NASA). This proposal followed the completion of a working level agreement between the scientists in the U.S.A. who are responsible for the WISP proposal, and scientists in Canada. The agreement is based on a recognized scientific interest of having an international team work together on a comprehensive wave-injection project which encompasses active experimentation at frequencies between the extra-low-frequency range and the very-high-frequency range, inclusively. The team together will provide guidance on matters of general concern. Within this team will be a group composed of the WISP/HR Principal Investigator and the WISP/HF hardware. This group comprises four Canadian

scientists, four U.S. scientists and one Australian scientist who have all agreed on their responsibilities in the project.

Canadian participation in Spacelab missions is motivated by a broad need to understand the atmosphere and plasma processes occurring in it. Mechanisms involving plasma waves play fundamental roles in the interaction of the ionosphere with the neutral atmosphere. Waves may control ionospheric motion or regulate the passage of energy through the ionosphere. Experimentation with a sophisticated wave injector is deemed to be a most useful way to study these basic mechanisms at short range. At the same time, the project provides further opportunity to improve space hardware technology. For example the operation of RF equipment at high power inside a magnetoplasma implies that a number of novel engineering challenges will have to be met.

On July 15 NRCC received authorization from Treasury Board to proceed with a program of space science projects including the WISP/HF project. The placing of a contract by DSS with SPAR Aerospace one month later meant that the Definition Phase was officially under way in Canada.

WISP/HF is a flexible Shuttle/Spacelab instrument for transmitting, receiving and processing signals in the 0.3 to 30 MHz range. The instrument consists essentially of a transmitter and associated phase-coherent receivers, all of which are controlled by a programmable microprocessor. The Orbiter-based transmitter works into a dipole of variable length and can deliver 0.5 kW peak power. The system includes a receiver on the Orbiter and another on the subsatellite, and will permit a wide range of plasma wave experiments in the ionosphere. Collaborative investigations using other WISP equipment (e.g., WISP/VLF) or other Spacelab facilities (e.g. charge-particle injection guns) are envisaged. The overall goal is to help build a comprehensive understanding of plasmapheric wave physics through group studies. NASA presently plans for a first WISP flight somewhere between 1984 and 1986.

CRC personnel have participated significantly in the WISP/HF project and its predecessors. Two of the 9-member science direction group for WISP/HF are from CRC. NRCC regards WISP/HF as the first part of an ongoing and evolving radio science program for the Shuttle era. The intention is to develop and maintain Canadian Space science expertise through such participation.

UNIVERSITIES

6. McMaster University (McMaster University Lunar and Planetary Science Program - H. Thode and C.E. Rees)

Isotopic anomalies in meteorites are proving to be unique indicators of the degree of heterogeneity of the primordial solar nebula and of the contributions to its makeup of material from different nucleosynthetic sources. This laboratory is undertaking a search for sulphur isotope anomalies in meteorites.

The lunar analysis program at McMaster is continuing. Measurement of sulphur concentrations and isotope abundances in grain size fractions of lunar soils gives information on the extent to which the samples have been exposed to the solar wind and to micrometeorite bombardment.

7. University of Alberta (Institute of Earth and Planetary Physics - G. Rostoker, J.C. Samson, M. Mareschal, K.S. Apps, B. Sullivan)

This year marked a change in the direction of the group's efforts from the data acquisition to the data analysis phase, with only one station of the IMS magnetometer array (Leduc) being still operative by the end of 1980. Midway through the year, Marianne Mareschal joined the group after spending the past three years at the Planetary Science Division, NRCC.

One of the more interesting studies completed this year was the analysis of the response of dayside Pc 5 pulsations to nightside substorm activity carried out by J.C. Samson and G. Rostoker. The primary observation in this study was the fact that the frequency of Pc 5 pulsations in the dayside auroral oval increased markedly within minutes of the onset of a sub-storm in the nightside magnetosphere.

G. Rostoker and J.C. Samson have also completed a study of the spectral characteristics of Pi 2 pulsations which occur on the nightside during the course of sub-storms. They found that, away from the region of the surge, the polarization characteristics were well-behaved with the change in sense of polarization in the horizontal plane across the resonance region from counterclockwise in the south to clockwise in the north.

Following on the study of the Ps 6 disturbances by G. Rostoker and K. Kawasaki, G. Rostoker and Joan C. Barichello completed a study of the diurnal and seasonal variation of Ps 6 variations. They found the maximum occurrence in local magnetic time occurred near dawn with a clear tendency for there to be stronger Ps 6 disturbances in the summer months than in the winter months.

G. Rostoker and K.S. Brathwaite have completed a study of the magnetic variations at high latitudes which have been associated with DP 2 disturbances. They were able to identify the equatorward ionospheric current flow south of the westward electrojet in the pre-noon sector and the poleward ionospheric current flow south of the eastward electrojet in the pre-midnight sector as part of the DP 2 current system.

G. Rostoker and B. Sullivan have completed a comprehensive study of afternoon sector Pc 5 activity. They found that these pulsations tend to occur as isolated bursts which appear to be triggered directly by solar wind effects.

J.C. Samson, M. Mareschal, G. Rostoker and K.S. Apps, have started to study the dayside response of the magnetosphere to nightside sub-storm activity. They are particularly interested in the possible changes in the net flow of current down field lines around local noon when sub-storm activity is observed around local midnight. Such a response of the currents would prove that there is indeed a connection between day and nightside ionospheric and field-aligned currents in the magnetosphere, the closing path of the equivalent circuit probably being the asymmetric ring current. Scandinavian stations are used to monitor nighttime activity while Canadian stations monitor the daytime magnetic field. Preliminary results indicate that there is a moderate amount of downward field-aligned current over the whole noon sector auroral oval even during quiet intervals.

J.C. Samson has continued his research in the area of multivariate time series analysis. The purpose of this research is to find objective methods to describe the statistical polarization states of waves, allowing a direct comparison of experimental data with theoretical predictions. Much of this research has been based on the analogy between quantum-mechanical descriptions of states, and the spectral representation of stochastic processes in multiple time series analysis

Up to this time the research here has dealt only with the descriptions of the states of second-order processes, since higher order processes (e.g., parametric instabilities) are not common in magnetospheric phenomena.

A second major area of research in multiple-time series methods has been the study and design of filters for the extraction of pure states (or polarized states) in multichannel data. Adaptive filters have been used with considerable success in studying dayside Pc 5's and Pi 2's accompanying auroral breakup events.

The adaptive filters have also been used, with some success, in filtering teleseismic seismograms and synthetic seismograms of interest to exploration geophysicists. A collaborative study with J. Briden of the University of Leeds (England) has shown the adaptive filters to be remarkably successful in removing the noise from multichannel, vertical component, teleseismic recordings of nuclear test events. Tests of the filter on multichannel, noisy, synthetic seismograms suggest that the filters may also prove useful in filtering seismic data for exploration work.

Recent work at this laboratory has focussed on the theory of optimum, adaptive polarization filters. In this theory we assume that the multivariate time series consists of an unknown pure state plus noise. The noise is specified in a stochastic sense, that is, we assume that only the invariants of the spectral matrix of the noise are known (i.e. if \underline{S} is the matrix of the noise, then we assume that $\text{Tr}\underline{S}^{\ell}$ ($\ell=1,n$) are known). Thus the noise can be any mixture of pure states or random noise. The solutions for the optimum filters are based on variational techniques in unitary (complex) spaces. Many of these methods can be adapted for the solution of inverse problems.

J.C. Samson has also embarked on a project to correlate auroral phenomena with their magnetic signatures during the course of a magnetospheric sub-storm. This research project has two major tasks. The first task is to develop numerical procedures for the detection of impulsive wavetrains, like Pi 2 micropulsations, in three component magnetometer data. The numerical filters appear to be quite successful in detecting Pi 2's.

The second task concerns the acquisition of ground based magnetometer data, and all-sky camera photographs of auroral activity in northern Alberta and the Northwest Territories. A field campaign was conducted in the interval October 22-25, 1979 in order to collect these data, using a manually operated camera system which was set up at Fort Smith, N.W.T. Ground based magnetometer coverage was obtained by reactivating magnetometer systems from the University of Alberta and located at Uranium City, Saskatchewan, Fort Smith, N.W.T., and Hay River, N.W.T. Additional coverage was provided by stations at Fort Providence, N.W.T., Fort Chipewyan and Leduc, Alberta. Data have also been obtained from the IMS ground based stations in North America.

The photographic campaign at Fort Smith was very successful. Complete coverage of an auroral breakup event was obtained for the night of October 24-25, 1979 and this film has now been developed. The exposures show in detail the formation of strong auroral arcs and breakup directly south of Fort Smith. Analysis of the magnetometer data has shown a strong Pi 2 event, coincident with the breakup. Work is still in progress to determine the localization of the Pi 2 pulsation over the North American continent.

8. University of British Columbia

(a) Geomagnetism and Aeronomy - T. Watanabe (Geophysics and Astronomy)

Two projects have been under way in the Aeronomy/Geomagnetism Group of the Department of Geophysics and Astronomy, U.B.C. One project concerns solar induced currents (SIC) and the other geomagnetic pulsation.

The SIC project originated in investigation of impacts of magnetic storms on a power transmission line running between Williston (Prince George) and Skeena, B.C. The power line, a Y-connected and 3 phase, is grounded at several substations through the neutral points of the power transformers there. SIC's, viz, geomagnetically induced quasi d.c. currents flowing into and from the power line through grounding, were observed at Williston together with geomagnetic field variations at a nearby location. Magnitudes of currents at 60 Hz, 120 Hz and 180 Hz were also observed at Williston. Size of SIC, scaled with its hourly range values, was found to increase by a factor of 2 approximately as Kp increases by 1. Magnitude of 2nd (120 Hz) and 3rd (180 Hz) harmonic currents were found to increase almost linearly with size of SIC. An investigation has been in progress to find strength of harmonic currents over a wider frequency range. One of our aims is to find whether or not power harmonic radiations at different frequencies are strong enough to use as source signals for E.M. prospecting of minerals. Another investigation which has been in progress is to carry out a magneto-telluric sounding using the SIC data. Knowing the d.c. resistance of the Williston/Skeena power line, we can convert the SIC data to those on surface potential gradient. Coupling the data with those on magnetic field variations, we can infer distribution of subsurface conductivity with depth. An inversion method has been successfully applied to find the conductivity-depth profile.

In investigation of geomagnetic pulsations, we have been analyzing two sets of magnetic data; one obtained from an IMS chain of stations in B.C., viz., Fort St. John, Prince George and Williams Lake, and the other from two locations in Saskatchewan, Rabbitt Lake and La Ronge, acquired during the period of the Pulsating Aurora Campaign. The IMS data from the B.C. stations concern three IPDP events. They were used to examine several different theories proposed for the origin of IPDP. The data from the B.C. stations make it possible to locate the source of the IPDP signal and its change with time.

9. University of Calgary (Department of Physics)

(a) X-Ray Astronomy

(i) Balloon Observations of High Energy X-Rays (20 keV)

Our program for the study of cosmic x-ray sources, above 20 keV, using balloon-borne payloads has continued. Our x-ray payload consists of four NaI (Tl) - CsI (Na) phoswiches with graded shield collimators (square $8^\circ \times 8^\circ$ FWHM, orientator, inclination 19°). The payload, ~ 190 kg (gross payload ~ 688 kg) was successfully launched from Hyderabad, India on October 31, 1980, using the ~ 6 million cubic foot balloon. It remained at ceiling altitude for approximately six hours. The payload was cut off and recovered. It needs refurbishing for the next launch. The sources sighted were NGC4151 and Hercules. The project is in collaboration with Tata Institute of Fundamental Research, Bombay, India (collaborators: D. Venkatesan and Chris Galas, U. of C., and S. Naranan, B.V. Sreekantan, S.G. Damle and P.K. Kunte). Chris Galas took part in the launch. The development of necessary software and the reduction of data is in progress.

(ii) Guest Observer on X-Ray Astronomy Satellite (HEAO-1)

This project, namely the study of 4 supernova remnants, SN1006, IC443, HB3 and 3C58 has been completed and has resulted in the award of a Ph.D. degree to Chris Galas. The project is in collaboration with G.P. Garmire of Cal. Tech., Pasadena, California (presently at Penn State University). Two manuscripts are in preparation.

(iii) Guest Observer Program on X-Ray Astronomy Satellite
(EINSTEIN)

The observations of Soft X-ray Source HB3 has been carried out and the results are being analyzed. (Collaborators: D. Venkatesan and C. Galas, U. of C., Knox Long, Columbia University and S. Naranan, TIFR, Bombay).

(b) Solar Terrestrial Relations

(i) Auroral X-Rays

Participation at La Ronge, Saskatchewan, in the Pulsating Aurora Campaign during January of this year unfortunately was not productive, as high upper atmospheric winds, unsuitable ground weather launch conditions and poor geophysical activity prevented launch of the payloads. The people involved are L. Varga, C. Galas and D. Venkatesan.

The analysis of data from the auroral x-ray payloads of 3 Black Brant IV rockets has been completed. The collaborators are K.K. Vij, J.S. Vogel and D. Venkatesan. A paper has been published in October 1980 in the Journal of Geophysical Research.

A review of the decade of balloon observations of auroral x-rays at the University of Calgary was presented at the Balloon Symposium of the COSPAR Meeting at Budapest, Hungary, June 1980. The manuscript is in press in the COSPAR Proceedings (1981).

(ii) Intensity Variations of Cosmic Rays and Solar Activity

A number of investigations during the year have been completed in collaboration with S.P. Agrawal, who was a Visiting Scientist for a year at the Herzberg Astrophysical Institute/-National Research Council of Canada, Ottawa. Another substantial collaborator in some of the studies was L.J. Lanzerotti from Bell Labs, Murray Hills, New Jersey, U.S.A. A number of papers are in various stages of review process for the Journal of Geophysical Research. Three papers have appeared in J.G.R. and G.R.L. In one investigation, an undergraduate in his third year (K. Volk) participated under the NSERC Undergraduate Summer Fellowship Program. The role of solar coronal holes in cosmic ray intensity modulation processes has been particularly dealt with. Some papers were presented at the American Geophysical Union Annual Meeting at Toronto during May 1980.

A comparative study in collaboration with J.A. Van Allen, Iowa, of Pioneer 10 data with Sulphur Mountain data has resulted in a publication (JGR, March 1980). The work highlights the contribution of Jovian electrons to the measured cosmic ray intensity in the interplanetary medium.

A preliminary study of Voyager 1 low energy cosmic ray data in collaboration with E.C. Roelof and S.M. Krimigis (Applied Physics Lab/Johns Hopkins University, Laurel, MD, U.S.A.) has been initiated. Presentation of a paper embodying some of the results relating to cosmic ray gradients was made at the AGU Meeting at San Francisco in December.

(c) Solar Far-Infrared Astronomy

(i) Stratospheric Far-Infrared Spectroscopy

Data analysis of far infrared spectra taken on Stratoprobe and University of Calgary balloon flights of the stratosphere in both emission and absorption between 1974 and 1979 is now virtually complete. Column densities of H_2O and O_3 in the stratosphere have been obtained from several altitudes and latitudes by analysis of the major pure rotational lines of H_2O and the Q branches of O_3 , while tentative identifications of possible emission features from constituents such as OH, NO_2 , HCl, and H_2O_2 have been made. Molecular line strengths for the magnetic dipole transitions of O_2 , triplets of lines of which appear in this spectrum, have been derived for the first time for many of these lines. These basic measurements, which are difficult to make in the laboratory, are important since this sequence of lines is used as calibration markers for H_2O and O_3 column density determination in stratospheric far-infrared work.

(ii) Far-Infrared Balloon-Borne Solar Astronomy

The University of Calgary balloon-borne solar telescope has now been completely redesigned and nearly rebuilt following its disastrous descent in June 1978. The primary optics is now a 32 cm on-axis Cassegrain design, fed by a servo-controlled heliostat mirror, and includes a completely new black-body calibration system for absolute spectrophotometry of the solar spectrum between 30 and 120 cm^{-1} . A high-resolution (0.03 cm^{-1}) Michelson interferometer is also being installed, which uses a new liquid helium cooled composite bolometer as the final detector. Improved features include automatic sensor gain control for sunset and sunrise tracking in support of stratospheric long-path absorption spectroscopy and fully steerable fine sensors for solar disc scanning and system optimization. First flight of this full system is planned for the spring of 1981; subsequent flights, one per year in support of a research programme of observations of both the quiet and active solar chromospheres is also planned.

(iii) Airborne Far-Infrared Solar Eclipse Photometry

Analysis is now complete on the eclipse photometry carried out from the NASA Lear Jet Observatory over the northern U.S.A. and Canada during the February, 1979 total solar eclipse. These data show no evidence of the limb spike reported earlier from results obtained over Africa from the Concorde aircraft, and fit closer to a flat intensity distribution over the solar disc, in contrast to recent solar atmospheric model predictions. This is interpreted as further evidence for inhomogeneity within the source region for this far infrared radiation, in the high photosphere and low chromosphere.

A second airborne eclipse expedition was made to Panama in August 1980 in the NASA Convair 990 "Galileo II" flying observatory, to observe the annular eclipse over the Pacific Ocean at far infrared wave-lengths. While data from this type of eclipse are somewhat more difficult to interpret, the initial indications from a comparison of observations with detailed modelling of the expected eclipse are that at 400 m the sun is virtually flat in emitted intensity, while active regions provided enhanced emission from one solar limb at 100 m producing an asymmetric eclipse curve.

Instrumental and navigational track design has already been carried out for a third airborne eclipse experiment, this time from Japan over the north Pacific Ocean in July 1981, again using the NASA Convair aircraft.

(d) Plasma Physics

Michael Schroeder and Ranga Sreenivasan have completed their investigation of the stability of a positive column sustaining a current under the most general conditions using a rigorous test due to Routh and Hurwitz generalised to complex coefficients. Theory predicts an instability when the drift velocity is $5/6$ times the electron thermal velocity, in excellent agreement with observations.

(e) Aeronomy: ISIS Group

(i) ISIS Auroral Imager Analysis

The tenth year of operation of our dual-wavelength auroral imager on the Canadian satellite ISIS-2 began on April 1, 1980. Spacecraft operations and processing of raw data are proceeding at a very low level, and nearly all of our effort recently has gone into the analysis of existing data. (20,000 passes). About 400 of the best passes have been transformed onto an ordered coordinate grid suitable for subsequent image display and analysis. In addition, a data base derived from about 1,000 intensity profiles at different magnetic local times has also been assembled.

Work on auroral morphology has continued with emphasis on the dayside cleft and, more recently, on the polar cap. Evidence is accumulating which supports the idea that so-called polar cap auroral arcs may actually belong to a greatly expanded auroral oval. If true, it solves the enigma of how arcs can form in two totally different regions of the magnetosphere and have the same characteristics and sometimes even join smoothly.

J.S. Murphree was the coordinator for the first of a four-volume set of coordinated data from the ISIS instruments. These volumes are expected to form the basis for much scientific work yet to come.

Technically, progress in visual display of the relationship between auroral features and spectral ratios has been achieved as also a system which enables data from G. Shepherd's 6300 Å instrument on ISIS to be compared with our own for image display.

(ii) ISIS Airglow Data

The analysis and interpretation of ISIS-2 airglow data have stimulated the development of a theoretical model of the global distribution and temporal variation of atomic oxygen in the 80 to 120 km region. We have been seeking an understanding of the large spatial and temporal variations in the observed airglow emission. For the polar cap airglow we have succeeded in relating several large enhancements to the occurrence of stratospheric warming events.

(f) Aeronomy: Other Projects

A study of the (NI)5200Å and (OI)6300Å airglow emissions was completed during the past year. We compared observations with calculations based on ionospheric measurements made with the incoherent scatter radar facility at Arecibo, Puerto Rico.

J. Meriwether and P. Hays of the University of Michigan have installed their 15-cm Fabry-Perot spectrometer at the Priddis Observatory (30 km southwest of Calgary). They are monitoring the dynamical behaviour of the thermosphere by measuring the Doppler width and shift of the (OI)6300Å emission line. They hope to acquire considerable information about the wind system at 50° N. We are cooperating with personnel from the University of Michigan in the operation of the facility.

A channel plate intensifier and CCD-based all-sky monochromatic auroral imager for ground-based observing has been constructed and is ready for field tests this winter. T. Morrison has started on an M.Sc. program which will employ the instrument in auroral studies.

(g) New Space Programs

Over the past year, a major effort has gone into preparation of two proposals, one to NASA for a combined visible and UV imaging system for the OPEN Mission and the other to the Swedish Space Corporation for a UV Imager to go on its VIKING satellite, scheduled to be launched in 1984 to investigate auroral particle acceleration processes. A Canadian proposal, put forward by NRC, to provide an ultraviolet imager for this mission has been accepted. Contract work to establish a baseline design started in November.

10. University of Victoria (Department of Physics)

Atmospheric Airglow Emissions

Studies of twilight lithium enhancements at Victoria are continuing, using a birefringent photometer.

Analyses of enhanced twilight emissions following the release of 1.4 kg of metallic lithium over northern Scandinavia during project CAMEO have been completed. As expected the enhancement was not spectacular, amounting to about 46 rayleighs (R) 77 hours after the release which took place on November 6, 1979, at a height of 961 km. The intensity then fell off at a rate of about 5 R per day to the background level of about 15 R in about 7 days. The results are being coordinated with observations made in France by M.L. Chanin, in Norway by D. Rees, and at Longyearbyen, Svalbard, by K. Henriksen, G. Sivjee and C. Deehr.

Much stronger enhancements were observed at Victoria following two rocket releases of metallic lithium at Poker Flat, Alaska on April 15 and 18, 1979. On this occasion two intensity peaks were observed, 190 R and 270 R, each occurring 5 to 6 days after the respective releases. These results are being further analyzed.

Although preparations were then made at four stations in Canada to photograph the Ba⁺ cloud and the Li cloud which were to have resulted from the release of these metallic vapours in outer space during project FIREWHEEL, this experiment ended in failure when the motors of the Ariane rocket failed shortly after lift-off during the launch on May 23, 1980.

A 1.5 m Ebert-Fastie type scanning spectrometer has been completed. The instrument is equipped with a sine-bar drive which provides a response which is linear with respect to wavelength. Wavelength tracking is accomplished by means of a shaft-position encoder which is coupled to a digital LED display unit giving a read out directly in Angstroms. It is planned to use the instrument for the calibration of spectral line sources.

11. University of Western Ontario (Centre for Radio Science)

(a) The Auroral Ionosphere

The ionospheric electron content was measured at La Ronge, Saskatchewan for a variety of auroral conditions during the Pulsating Aurora Campaign in February of 1980. The two-frequency differential phase technique was used with the NNSS satellite beacons. Comparisons of optical data and the radio results indicate that for quite strong pulsations the electron content is modulated by less than two percent.

An additional involvement during the pulsating aurora campaign was with the SRFB ionosonde. Virtual-height-versus-time (h't) measurements were done during the entire campaign at a fixed frequency of 2.8 MHz using some additional circuitry installed in the back of the ionosonde. These measurements were used in conjunction with a model study of the ionospheric response to pulsating auroral particle input. It was found that the h't measurements could be used to give information about the energies and fluxes of the incoming auroral particles.

(b) Electron Content During 'Waterhole'

The 'Waterhole' rocket launched from Churchill carried a C.R.S. two-frequency coherent beacon package which was ejected at 80 km and travelled an independent trajectory close to that of the parent rocket. While there is evidence that the electron concentration in the immediate neighbourhood of the explosion dropped as expected, the more dramatic outcome was the sudden cessation of particle precipitation.

(c) Ionospheric Structure and Communications

The basic differential phase measuring system has now been operated successfully at London, La Ronge, Churchill, and Cambridge Bay. When used with orbiting satellite beacons this system essentially provides a horizontal profile to total electron content. With suitable analysis techniques and/or two station observations, details of ionospheric irregularity structure are obtained. A more sophisticated version of the system, interfaced with a mini-computer, is about to be put into operation at London for a long series of observations aimed at a comprehensive description of the ionospheric environment, at mid-latitudes, for UHF satellite-to-ground communication purposes. It is intended at a later date to repeat the series of observations at high latitudes for the same purpose.

Some preliminary results from pilot observations have been passed to the industrial contractor for Sarsat to assist in evaluating the accuracy of the Sarsat system in locating downed aircraft beacons.

(d) Long-Line System for Measurement of Ionospheric Electric Fields

The improved long-line system became fully operational during spring of 1980. A data sampling between February and May gave convection drifts which agree well with the average spring results obtained by the Millstone Hill incoherent scatter radar.

An additional set of measurements using the long-line technique was obtained during a summer mini-campaign with J. Koehler from University of Saskatchewan to Southend, Saskatchewan. Approximately three weeks of measurements were done from this location looking at an ionospheric region near $60^\circ\lambda$. Initial results from these measurements show that the east-west convection pattern at this higher latitude is significantly different from the convection pattern measured from London.

(e) UHF Radio Aurora

Work has continued on the analysis and interpretation of data obtained during 1976 and 1978 from SRI International's 398 MHz radio-auroral radar at Homer, Alaska. That facility is now permanently closed, so no further data will be available.

A detailed study has been made of one two-hour period of radar echoes which were obtained at the same time as the Chatanika incoherent scatter radar was making spatially coincident measurements of electron density and electric field. There does not seem to be a direct relationship between the radio-auroral Doppler velocity and the line-of-sight component of the electron drift velocity, as has been observed at VHF.

A theoretical study of the propagation and growth of plasma waves, particularly at angles away from perpendicular to the geo-magnetic field has led to some surprising results, which arise because of the extremely rapid variation of the phase velocity with off-perpendicular angle.

Another study also in progress is a statistical survey of a large quantity of Doppler observations, covering the complete range of elevation, azimuth and local times available in the data. One interesting result is a trend to smaller Doppler velocities at larger off-perpendicular angles.

12. York University (Department of Chemistry)

(a) Stratospheric Odd Nitrogen: Nitric Oxide Measurements at 32° N in Autumn

Nitric oxide was measured, by chemiluminescence, over the altitude range 14 to 40 km during three balloon flights from Palestine, Texas in fall of 1977 and 1978. The three height profiles were quite similar as were the height profiles of ozone and temperature. Our three profiles agree reasonably well with those generated by 1-D models at the upper end of the altitude range of the measurements but are higher than the model profiles at the lower end of the altitude range.

(b) Stratospheric Odd-Nitrogen: No Measurements at 51°N in Summer

The altitude distribution of nitric oxide was measured during three balloon flights in August of 1976 and 1978. Median values of the volume mixing ratio at 18, 24, 30 and 34 km were 0.4, 1.4, 6.5 and 13 ppb, respectively. The data are discussed in relation to average profiles of other odd-nitrogen species measured for this season and latitude and in relation to current one-dimensional photochemical models of the stratosphere.

IV VOLCANOLOGY

Compiled by: B.N. Church

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1. Introduction

Among the investigations in progress ranging from stratigraphic studies, mapping, petrology, geochronology and mineral research many are focused on the Cordillera region, although volcanology is also well reported on the Precambrian Shield from the Northwest Territories to the Archean greenstones of Ontario, and ophiolites of southwest Newfoundland. Forty-one reports are presented from 12 institutions including federal and provincial government groups and good representation from universities. Owing to the great diversification of studies, institutional reporting is here employed for simplicity and brevity.

2. Geological Survey of Canada

(a) Natkusiak basalts, Victoria Island, N.W.T. (W.R.A. Baragar)

The Natkusiak basalts are the only known surface expression of the Franklin magmatic event of late Hadrynian age. They are important, therefore, as a stratigraphic standard to which the widespread Franklin dykes and Coronation sills might be related. The sequence is about 800 m thick to an eroded upper surface and comprises a monotonous succession of subaerially erupted plateau basalts. The rocks are slightly under-saturated tholeiitic basalts typically containing less than 10% normative olivine and less than 5% modal olivine. They show a slight but significant decline in MgO upward in the sequence. An accompanying study is being done on the paleomagnetism of the sequence by Palmer, et al. (see section on paleomagnetism).

(b) The Circum-Ungava Belt of Cape Smith and the Islands of Eastern Hudson Bay (W.R.A. Baragar)

The study comprises the volcanic stratigraphy and petrology of the western half of the Cape Smith Belt, the Ottawa Islands, the Sleeper Islands, and Belcher Islands. In the Cape Smith Belt a shallow-water sequence of massive and pillowed basalts is overlain by a thick succession of seemingly deep-water, pillowed komatiitic basalts. The latter succession can be traced westward through Smith Island into Hudson Bay and reappears in the Ottawa Islands where it includes several layers of spinifex-textured flows identical in internal structure to the classical spinifex flows of Munro Township. The primary mineralogy is not there preserved but chemical analyses through one of the peridotitic komatiite flows is more suggestive of pyroxene than olivine spinifex. The Sleeper and Belcher Islands appear to lie on the craton side of the projection of the komatiitic unit southward and the tholeiitic basalts

which form the Flaherty Formation of the Belcher Islands and its correlative on the Sleeper Islands are probably equivalent to the earlier tholeiites of the Cape Smith Belt.

- (c) Geology of Red Indian Lake, west half, Newfoundland (R.K. Herd)
- (d) Geology of Island Lake map-area, Manitoba and Ontario (R.K. Herd and I.F. Ermanovics)
- (e) Geochronology of young volcanic centres (J. Souther, R.L. Armstrong, J. Harakal and K. Scott)

J. Harakal, K. Scott and R.L. Armstrong are working with Jack Souther (GSC) on the dating of young volcanic centers - mostly in the Stikine and Garibaldi belts of B.C. Present work is concentrated on Mount Edziza.

- (f) Geothermal reconnaissance in the central Garibaldi Belt, British Columbia (J. Souther)

3. Ministry of Energy, Mines and Petroleum Resources,
Province of British Columbia

- (a) Tertiary Outliers of the Okanagan-Boundary Region (B.N. Church)

Detailed mapping of Tertiary outliers of the Okanagan - Boundary region is continuing (1:50,000 scale). Five maps have been published and three more are in preparation. As a result of this mapping the name Penticton Group has been suggested, embracing six well defined formations having an aggregated thickness of about 2500 m with an age range from 48.4 Ma (whole rock) to 53.1 Ma (biotite) (K-Ar determinations).

- (b) A Survey of Cenozoic Magnetostratigraphy in South-Central British Columbia (B.N. Church)

In conjunction with ongoing mapping projects, preliminary magnetostratigraphic studies show a persistence of normal polar orientations in the sections of Eocene lava in the Okanagan area and a number of interesting polar reversals in the Mio-Pliocene basalts near Kelowna and Vernon.

- (c) Anomalous uranium in the Summerland cauldrea and near the Riddle Creek volcanic centre (B.N. Church)

This is an ongoing project with additional investigations to be completed in the Riddle Creek area.

- (d) Petrology of schackanite lava (B.N. Church)

The frequent occurrence in some areas of British Columbia of primary analcite in mafic phonolite lava (shackanite) is well documented. Some amplification in the field of experimental petrology is required to further explain this phenomenon.

- (e) Evaluation of geothermal potential of the Tertiary volcanic-sedimentary basins of south-central British Columbia (B.N. Church)

Warm water potential is being investigated for space heating purposes to supply the needs of Interior municipalities adjacent to Tertiary volcanic - sedimentary basins in the Thompson, Okanagan, and Boundary regions of southern British Columbia. Development of thermal reservoirs in the Tertiary basins is believed to be due to low thermal

conductivity of blanketing Tertiary strata compared to the high conductivity of basement crystalline rocks.

- (f) Paleo-combustion of coal and the resulting metamorphism and production of lava-like slag (B.N. Church, A. Matheson and D. Hora)

Lava-like slags formed from the paleo-combustion of coal deposits have been identified in the Hat Creek, Princeton and Telkwa areas. Several reports have been published on this subject supplying geological, mineralogical and chemical data.

- (g) Investigations on the classification of volcanic rocks (B.N. Church and W.M. Johnson)

The refractive index, whether determined directly from artificially fused rock glass or by calculation, is a measure of basicity that provides a ready means of linking microscope observations with chemical composition to assist classification, petrological interpretation, and mapping of volcanic or other aphanitic igneous rocks.

The prediction of refractive index directly from silicate analysis has been achieved by replacing the specific gravity factor in Larsen's version of the classical Gladstone-Dale relationship by a set of new empirically derived refractivity coefficients for the major oxides.

- (h) (Helikian) Proterozoic Purcell Supergroup in southeastern British Columbia, stratigraphy, sedimentation and mineral deposits (T. Hoy)

Included in the Belt-Purcell succession is a basaltic lava-volcaniclastic sequence of Helikian age that has been informally called the "Purcell lava". Regional mapping of the terrain including the "Purcell lava" has furthered our knowledge of its distribution and character.

- (i) Ordovician volcanics of the Kechika Trough and their relationship to bedded barite deposits (D. MacIntyre)

This project is an ancillary study related to a larger project involving mapping and stratigraphic studies of Paleozoic sedimentary strata of the Kechika Trough in northeast B.C. The Ordovician volcanics are related to inter-basin rifts and appear to be calc-alkaline in composition. Bedded barite deposits occur in the same part of the section elsewhere in the area and through paleontological and K-Ar dating techniques it is hoped to show that the volcanism and barite deposition were contemporaneous events.

- (j) Geochemistry of Upper Cretaceous volcanic rocks, Tahtsa Lake area, west central B.C. (D. MacIntyre)

This project involves whole rock and trace element analyses of volcanic rocks from the Tahtsa Lake area. The object of this work is to show trends in the geochemistry of volcanic rocks deposited at various stages in the evolution of the Tahtsa Lake caldera and to compare these trends with coeval plutonic phases.

- (k) Geochemistry of the Chu Chua deposit (W.J. McMillan)

This pyritic massive sulphide deposit occurs in association with tuffaceous cherts in tholeiitic marine basalts of the Late Paleozoic Fennell Formation. The geochemistry of the ore and enclosing rocks is being studied.

- (l) Nicola project, south-central B.C. (W.J. McMillan and V.A. Preto)

This study is concerned with the stratigraphy, geochemistry and mineral deposits of the Late Triassic Nicola Group.

- (m) Sylvester Group greenstones as hosts for gold deposits, Cassiar B.C. (A. Panteleyev)

The Mississippian to Permian Sylvester Group is a greenstone (basalt-andesite) - argillite-chert assemblage that is host to numerous small auriferous quartz veins. The geological setting is being studied and comparisons made with Archean-type gold deposits.

4. University of British Columbia

- (a) Petrology, geochemistry and geochronology of Cretaceous and Cenozoic volcanics (R.L. Armstrong and Associates)

Late Cenozoic volcanic rocks from throughout B.C. have been analyzed by K. Scott and R.L. Armstrong for Rb, Sr, and $^{87}\text{Sr}/^{86}\text{Sr}$. A subset of these will have ^{18}O measured by K. Muhlenbachs (U. of Alberta), and eventually Pb and Nd done at UBC.

J. Haraçal, K. Scott and R.L. Armstrong have dated mafic intrusive rocks (Oligocene and Miocene) in and near Vancouver for paleomagnetic studies of J. Monger (GSC) and E. Irving (EPB) and plateau lavas in central B.C. for Ph.D. thesis studies of M.L. Bevier (Univ. of Calif. at Santa Barbara) and R. Parrish (at UBC).

Bob Lawrence completed an honours thesis on alkaline volcanic rocks at the north end of the Garibaldi belt (chemistry, K-Ar dating, Sr isotopes). Helen Grond and Sheila Churchill did similar studies of the Cretaceous Mount Nansen and Carmacks Group volcanics of the Yukon. Doug Wood is currently working on Cretaceous volcanic rocks from the Mackenzie Mountains.

Rob Berman completed his M.Sc. thesis on the Miocene Coquihalla Volcanic Complex of the Pemberton Belt and Tom Ewing his Ph.D. thesis on the Eocene Kamloops Group. Numerous papers from these studies are in press.

G. Nixon is writing up the results of his thesis work on Iztaccihuatl Volcano and other Quaternary volcanic rocks of the Trans-Mexican Volcanic Belt.

- (b) Mapping, stratigraphy and geochronology of Cenozoic volcanic rocks (W.H. Mathews and associates)

W.H. Mathews has recently published or submitted papers that include K-Ar dating of early to late Cenozoic volcanic rocks in the Quesnel area and Cascade Mountains. Also, Mathews and Rouse were engaged in June 1980 in mapping and sampling the early to mid-Tertiary volcanic and sedimentary rocks of the Gang Ranch-Empire Valley area of central B.C. with a view to extending the stratigraphy and palynological work started in the Quesnel area a few years ago.

- (c) Thermodynamics of silicate melts (R. Berman and T.H. Brown)

R. Berman is now working with T.H. Brown as advisor on a Ph.D. thesis project entitled "Thermodynamics of silicate melts". Activity-composition relationships will be derived for multicomponent silicate melts so that quantitative modelling of igneous rock systems can be pursued. The model used in this study relies on linear programming

techniques to derive a set of Margules parameters for a liquid oxide component which are consistent with all available experimental data on liquid-solid equilibria in simple and complex systems.

(d) Geochemical and Sr isotope studies (Zhou Xinghua)

Zhou Xinghua, from the State Seismological Bureau, Peking, China, is working on chemistry and Sr isotope analyses of Cenozoic volcanic rocks of eastern China.

5. University of Alberta

- (a) The geology and geochemistry and sulphur isotopes of the Anyox massive sulfide deposits (Robert J. Sharp)

Tholeiitic metabasaltic pillow lavas either host or underlie the Hidden Creek, Double Ed, and Bonanza massive pyrite-pyrrhotite-chalcopyrite orebodies at Anyox, British Columbia. The Hidden Creek deposit is composed of five tabular cupriferous iron sulfide bodies, lying along the volcanic-sedimentary contact, which are partially underlain by altered metabasalt containing disseminated copper mineralization and some quartz stockworks. The Double Ed and Bonanza deposits are narrow, pipe-like orebodies mineralogically identical to the Hidden Creek deposit but are hosted by pillowed metabasalt and occur 150 m stratigraphically below the main volcanic-sedimentary contact.

Major element analyses were made and show the original basaltic magma to have been tholeiitic. Altered basalts have gained iron, sulfur and magnesium but have lost calcium, silica and sodium. Sulfur isotopes in the three deposits fall in the +1.5 to +1.67 ‰ ^{34}S (0/00) range.

- (b) The petrology of the Heart Peaks volcanic centre, north-western British Columbia (J.J. Casey and C.M. Scarfe)

6. University of Calgary

- (a) Petrology of nephelinites (J. Nicholls and M.Z. Stout)
(b) The heat effects of H_2O in magmas (J. Nicholls and M.Z. Stout)
(c) The White River ash, Yukon Territory; a petrologic study (Hilary Downes)

7. University of Saskatchewan

- (a) Aphebian Island arc volcanism, Flin Flon area (L.C. Coleman, M.R. Stauffer and N.T. Arndt)

Detailed petrographic, geochemical and stratigraphic studies of the volcanic succession in a small area centred about Flin Flon, Manitoba and Creighton, Saskatchewan are being carried out. It is hoped that these studies will provide a basis for comparing the character of Aphebian Island arc volcanism with that of island arc volcanism of other ages.

8. University of Manitoba

- (a) Missi Island volcanic centre, Amisk Lake, Saskatchewan (L.D. Ayres and W.J. Ferreira)

During 1980 work continued on documentation of the stratigraphy of the Proterozoic Amisk volcanic sequence near Flin Flon. Emphasis to date has been on the lower mafic section that, although interrupted by numerous small faults, seems to be a reasonably complete record of the

evolution of a basaltic to andesitic shield volcano. The mafic section includes two subaerial and two subaqueous periods of eruption with littoral and flowfoot breccia units marking the former shorelines. Emphasis of this part of the project is on better documentation of the subaqueous-subaerial transitions and comparison of subaqueous and subaerial flows and fragmental rocks.

Work has been initiated in the overlying andesitic to dacitic stratovolcano, but stratigraphic continuity is interrupted by major faults. Massive to brecciated and locally pillowed, stubby dacitic flows form a major part of the examined sequence. The morphology of these flows will be better documented in 1981.

9. Laurentian University

- (a) 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)

Carbonate alteration and hydrolysis of mafic volcanic rocks in the Timmins area have been accompanied by mobilization and redistribution of alkalis, CaO, MgO and FeO. These major oxides are of dubious value in classifying the volcanic rocks and are of no value in identifying and correlating lithostratigraphic units. The trace elements Y, Zr, TiO₂ and Cr, whose fractionation tendencies parallel those of the alkalis, FeO and MgO, are relatively immobile and display characteristic patterns within different volcanic units. The trace-element patterns are highly diagnostic and their distribution corresponds to the distribution of lithostratigraphic units. Immobile trace-element data represent a potentially valuable tool in stratigraphic correlation of Archean volcanic rocks, whether altered or unaltered.

10. University of Western Ontario

- (a) The evolution of an Archean volcanic-plutonic complex (G.R. Edwards and R.W. Hodder)

A relatively complete Archean felsic to intermediate volcanic-plutonic complex at Pipestone and Dash Lakes, District of Kenora, Ontario, has been mapped and affords an opportunity to study local magma genesis and sequential development. Major and trace chemical analysis of the rocks and minerals supplements the field data.

11. Carleton University

- (a) Geology of the Hotailuh Batholith and surrounding volcanics, north-central British Columbia (R.G. Anderson)

Upper Triassic Stuhini Group (Souther, 1971, 1977) and unnamed Triassic-Jurassic volcanics fringe and form pendants within the Hotailuh Batholith. The age, stratigraphy and geochemistry of these two volcanic units are being investigated as part of a Ph.D. thesis concerning the magmatic history of this composite batholith in the Cry Lake (104I), Dease Lake (104J) and Spatsizi (104H) map-areas in north-central B.C. The age of the various plutons and their geological relationships with these two volcanic suites provide constraints on their poorly known fossil ages.

- (b) Volcanic cyclicity and stratigraphy, Belmont Township, southern Ontario (James R. Bartlett)

The study area lies in the southwesternmost part of the Grenville Province in Ontario. Approximately one-half of Belmont Township is

underlain by Precambrian rocks, of which most are metamorphosed volcanic and volcanogenic types. The meta-volcanic rocks, which generally comprise mafic and intermediate flows and intermediate to felsic pyroclastics, appear to be assignable to three distinct mafic to felsic volcanic cycles.

The main thrust of the thesis involves field mapping, at 1:15,840, of the volcanic cycles and their associated non-volcanic rocks, with the goal of delineating stratigraphic relationships and paleo-environment. Petrographic and petrologic interpretations will be based on the field mapping and the examination of samples, including at least seventy-five thin sections. Chemical analyses of at least forty samples may enable distinction among the cycles, and should shed some light on magma sources and intra-cycle trends.

- (c) The boundary between the Omineca Belt and the Intermontane Belt in the Quesnel Lake area, east-central British Columbia (C.J. Rees)

Field mapping of the area began in 1980, and evidence of a major shear zone was found at the boundary (Rees, 1981). The Omineca Belt to the east of the boundary comprises presumed Upper Proterozoic metasediments and 'bodies' of granitoid gneiss. West of the boundary, the Intermontane Belt comprises presumed Upper Paleozoic 'greenstone' (Antler Formation) at the base, followed by Upper Triassic Black Phyllite (informal name). The youngest and most westerly unit in the area consists of Upper Triassic to Lower Jurassic volcanics, volcanoclastics and sedimentary rocks (Takla Groups, after Tipper, et al., 1979). The preliminary interpretation is that Intermontane Belt rocks were thrust (obducted) eastward onto the western margin of the Omineca terrane in the Middle Jurassic (see Montgomery, 1978).

- (d) The Late Cretaceous-Tertiary volcanic complex of Montana Mountain, south Yukon (Charles F. Roots)
- (e) Lithofacies and eruptive history of the Narakay Islands Volcanic Complex, Proterozoic, Northwest Territories (Gerald M. Ross and J.A. Donaldson)

The Narakay Islands, located in Dease Arm of Great Bear Lake, are composed of quartz arenites, stromatolitic dolostones and mafic volcanoclastics of the 1.5 Ga old Hornby Bay Group. The sedimentary rocks are more than 500 m thick and record deposition in a shallow subtidal to intertidal setting. Phreatomagmatic events deposited a variety of pyroclastic facies (agglomerate, pyroclastic surge, bedded lapilli tuff) that underwent minor amounts of marine reworking. Intrusive explosion breccia bodies and diatreme-like breccia pods and pipes were associated with the volcanic episodes. Primary textures and facies relationships have not been affected by metamorphism or deformation and exposure of the complex is greater than 90%. Thus it is an ideal area to examine and document facies relationships and depositional processes. One month of detailed mapping is planned for the summer (1981) to be followed by petrographic and laboratory analysis.

12. Memorial University

- (a) The petrology and geochemistry of the Annieopsquotch ophiolite, southwest Newfoundland (G.R. Dunning)

- (b) Hilina Formation-Kilauea Volcano, Hawaii (R.M. Easton, M.O. Garcia and F. Frey)

This is a study of the petrology and geochemistry of the 20,000 year old and older lavas of Kilauea Volcano, Hawaii. Includes major, trace and REE geochemistry.

- (c) Stratigraphy and volcanic geochemistry of the Akaitcho Group: an initial rift sequence in Wopmay Orogen (early Proterozoic), N.W.T. (R.M. Easton)

This is a study of the stratigraphy and geochemistry of the 1800-2000 Ma Akaitcho Group. The Group consists of continental tholeiite and ocean tholeiite basalt interbedded with continent derived clastic rocks. These rocks may be related to the initial development of an early Proterozoic continental margin.

- (d) The LaBine Group, Great Bear Lake, N.W.T.: an early Proterozoic continental volcanic arc in Wopmay Orogen (R.S. Hildebrand)

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V ISOTOPE STUDIES AND GEOCHRONOLOGY

Compiled by: A. Hayatsu

1. Bedford Institute of Oceanography,
Chemical Oceanography Division,
Atlantic Oceanographic Laboratory
 2. University of British Columbia,
a) Department of Geological Sciences;
b) Department of Geophysics and Astronomy
 3. Dalhousie University, Department of Physics and Geology
 4. McGill University, Department of Geological Sciences
 5. McMaster University,
a) Department of Chemistry;
b) Department of Geology
 6. Queen's University, Department of Geology
 7. University of Western Ontario, Department of Geophysics
 8. University of Alberta, Department of Physics
 9. University of Toronto, Department of Physics,
Geophysics Laboratory
 10. Bibliography
1. Bedford Institute of Oceanography - Chemical Oceanography Division,
Atlantic Oceanographic Laboratory (F.C. Tan and P.M. Strain)

- (a) Sources, pathway and behaviour of organic matter in the St. Lawrence Estuary

Sources, sinks and the distribution of organic carbon in the St. Lawrence Estuary, Canada have been examined by stable carbon isotope ratio analysis. Characteristic ranges of $\delta^{13}\text{C}_{\text{PDB}}$ values are found for particulate organic carbon (POC) samples from different sectors of the study area.

On the basis of the $\delta^{13}\text{C}$ evidence, we conclude that the POC in the upper St. Lawrence Estuary is dominantly of terrestrial origin.

The unusual $\delta^{13}\text{C}$ of POC in the lower Estuary may result from high carbon demand during periods of high biological productivity or from a change in the dominant planktonic species with an associated change in isotopic fractionation behaviour.

- (b) Sources and behaviour of organic matter in the Eastern Canadian Arctic

The sources and behaviour of organic matter in suspended solids and underlying sediments are examined by stable carbon isotope analysis of plankton, particulate organic matter, dissolved CO_2 and recent sedimentary materials. The analytical aspects of this work, with the exception of some sediment samples which require further laboratory study, is essentially completed. The interpretation of the results is underway. The samples investigated in this study were collected in 1977 and the area covered Baffin Bay, Lancaster Sound, Jones Sound and Smith Sound.

- (c) Further work on $^{18}\text{O}/^{16}\text{O}$ sea ice meltwater studies in the Arctic

A paper that discusses the application of $^{18}\text{O}/^{16}\text{O}$ method to the study of sea ice meltwater in the Canadian Arctic, principles and limitation for the detection of brines and the sources of water of Baffin Bay bottom water has been published in Journal of Geophysical Research.

Further work on the sea ice meltwater studies are being contemplated. With the assistance and collaboration of MEL scientists, water and glacial samples were collected from Hudson 1980 cruise to the Eastern Canadian Arctic. In addition, samples collected from Lancaster Sound, together with samples analyzed in two previous years, will provide information on the year-to-year variations in the sea-ice meltwater distribution.

- (d) Stable carbon isotope studies in Pecks Cove Mudflat Ecosystem, Bay of Fundy

This is a cooperative project with Dr. D. Gordon of Marine Ecology Laboratory and P. Schwinghamer of Dalhousie University. Stable carbon isotope ratio methods are being used to determine the following:

(i) the relative importance of different potential organic carbon sources to the total particulate organic carbon content of surface sediment and flooding seawater and how it varies seasonally.

(ii) the relative importance of these different carbon sources to consuming organisms feeding on the mudflat.

Samples are being collected monthly by MEL scientists. After preparation, samples will be analyzed for δC^{13} at the stable isotope laboratory of Chemical Oceanography Division. Samples that are being collected include benthic diatoms, phytoplankton, spartina, seaweeds, surface sediments, suspended particulate matter, and animals feeding on the mudflat. Preliminary results indicate that there are significant C^{13} differences among the potential carbon sources.

- (e) Stable isotope paleoclimatology studies on Newfoundland Slope

This is a collaborative project with Dr. C.T. Schafer of the Atlantic Geoscience Center.

The bottom water samples and benthic foraminifera in unbioturbated sediment cores (as shown by Pb-210 method) collected from the Newfoundland slope during AGC cruises in 1978 and 1979 are being analyzed for O^{18}/O^{16} ratios to examine the climatic changes during late glacial and Holocene time. The living benthic foram from the box cores and fossil forams from various horizons in the sediment cores have been separated. The O^{18}/O^{16} analysis of the bottom water (Western Boundary undercurrent) has been completed. A special purification line for the removal of organic contaminants in foram carbonate has been constructed. This project is at a very preliminary stage.

- (f) Scotian Shelf ecosystem studies

An exploratory study using stable carbon isotope ratio methods to study the food chains in the Scotian Shelf ecosystem is being carried out in collaboration with Dr. E. Mills of the Department of Oceanography, Dalhousie University. This work is at a very preliminary stage.

2a. University of British Columbia - Department of Geological Sciences
(R.L. Armstrong)

- (a) Coast Plutonic Complex

R. Parrish has completed fission track dating to determine cooling and uplift history of the Coast Plutonic Complex and now has begun analysis of tectonic and thermal models. Study of the Bella Coola and Alice Arm traverses is continuing with $Rb-Sr$ rock and mineral isochrons. These will be supplemented later with U-Pb zircon dates.

P. van der Heyden has completed mapping in the Tsaytis River area and is now doing chemical and isotopic analysis of Gamsby Group metavolcanic rocks, deformed plutons, and central gneiss complex.

(b) Insular Belt

Sr isotopic analysis of Leech River schist samples has demonstrated their close similarity to the Franciscan rocks of California. Only a younger metamorphic overprint (Eocene) distinguishes the Leech River rocks.

(c) Omineca Belt

Papers by R. Parrish on the Nemo Lakes area on the north side of the Valhalla dome and W.H. Mathews on Eocene resetting of Shuswap rocks near Enderby have been submitted for publication.

B. Ryan has analysed 5 zircon samples from Eagle Bay Formation volcanic rocks that give an age of 380 Ma (or slightly older) for the volcanic activity. This agrees with Sr isotopic data for the same rocks and is only slightly older than granitic intrusive rocks of the same region, dated 372 Ma by the GSC. A Devonian volcanic arc, of uncertain original relationship to the North America craton, is indicated.

Zircon dates done by B. Ryan for nepheline syenite of the Jordan River area and of porphyritic granodiorite in the Valhalla dome show resetting by late Mesozoic sillimanite-grade conditions of metamorphism.

(d) Cascade Mountains

The duality of blueschist ages in the North Cascades (late Paleozoic and Jura-Cretaceous) (Armstrong, 1980) has been further confirmed by dating in the Nooksack River and Mount Watson areas. Darrington Phyllite Sr isotopic characteristics are exactly like those of the Franciscan rocks of California, implying a common history and tectonic parallelism of the two areas.

(e) Pb Isotopic Studies

C. Godwin, A. Sinclair and B. Ryan have continued their program of ore Pb studies related to Cordilleran mineral deposits.

(f) Terrestrial Geochemical Evolution

A review paper exploring arguments for long-term crustal recycling via subduction (in contrast to the fairly widely held idea of continental growth) was written during the past year and presented at two meetings in Europe (Armstrong 1980).

(g) Other Projects

Petrologic, chemical and isotopic work on volcanic rocks in the Canadian Cordillera and Mexico are described in the volcanology section of this report.

Multiple method dating has been applied to problems of structural chronology in the Whipple Mountains, Southern California; to determine basement and volcanic cover ages in southwestern Mexico; and to determine the ages of volcanic and plutonic rocks in the Yukon and Intermontane Belts of the Canadian Cordillera.

2b. University of British Columbia - Department of Geophysics and Astronomy
(W.F. Slawson and B.D. Ryan)

Twelve new lead isotope analyses of samples from the West and East Shasta districts, California are presented. Isotopic ratios $^{206}\text{Pb}/^{204}\text{Pb}$ vs $^{207}\text{Pb}/^{204}\text{Pb}$ exhibit a good linear trend with a slope of 0.1804 ± 0.0088 . Arguments are presented that the model ages calculated from this slope are not real. Therefore, the ore must either reflect an inherited mantle-isochron or a mixture of mantle lead with pelagic sediments. In this light it is questioned whether Precambrian geochronology based upon lead isotopes from volcanogenic deposits is valid.

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

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

(i) Ages of paleomagnetic poles. Biotites and hornblendes from various rock units from the island of Newfoundland have been dated by the $^{40}\text{Ar}/^{39}\text{Ar}$ stepwise outgassing method. These rock units (for example, diabase dikes from the Wesleyville area and the Mount Peyton granite-gabbro complex) are generally characterized by more than one stable remanence direction. Initial results suggest that the earliest phases of the Mount Peyton complex may be up to 40 Ma older than the late phases. These data can be used to estimate the rate of apparent polar wander in Silurian-Devonian times (with P. Lapointe, Earth Physics Branch, G.S. Murthy, Memorial University and Honours student, W. Morgan). Similar studies on rocks from Nova Scotia's Meguma Zone are now underway in an attempt to learn more about the origin and tectonic history of this exotic block of Appalachia.

(ii) Metamorphic and intrusive events in southwest Nova Scotia.

Our paper summarizing results of over 40 K-Ar and $^{40}\text{Ar}/^{39}\text{Ar}$ analyses of micas from the granitic phases has been accepted for publication by the Canadian Journal of Earth Sciences. Current studies are concentrating on the metamorphic rocks. Honours student, M. Savell, has recently completed a thesis in which the effect of variable silt contents on $^{40}\text{Ar}/^{39}\text{Ar}$ gas release patterns was investigated (with D.B. Clarke, G.K. Muecke, M. Zentilli).

(b) Stable Isotope Studies

Our Micromass 602D mass spectrometer is now equipped with an on-line small sample (down to 0.1 mg) carbonate preparation system. Projects now underway include:

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

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

4. McGill University - Department of Geological Sciences (R. Doig and A.D. Fowler)

(a) Cape Smith Project (R. Doig)

The Cape Smith volcanic belt extends some 350 km across the Ungava Peninsula of Quebec, and is a part of the Aphebian Circum-Ungava geosyncline. Preliminary work has indicated extensive areas of Archean basement (2,800 Ma) as well as clearly metasedimentary units which may be equivalent in age to the dominantly volcanic rocks of the Cape Smith belt.

(b) Regional Geochronology, Grenville Province (R. Doig)

We have recently studied a 250 km section along the North Shore of the Gulf of St. Lawrence from Sept Iles to Havre St. Pierre which consists of abundant plutonic rocks ranging from the highly deformed Havre St. Pierre anorthosite to late-orogenic granites and syenites and three supracrustal units (metagreywacke, metabasalts, and migmatitic leucocratic paragneisses). Rb-Sr ages (of the paragneisses and of deformed granitic rocks) are concordant at about 1100 Ma. Other notable results are the 1350 Ma age of the metagreywacke and the unexpected abundance of large masses of very late granitic and syenitic rocks emplaced 950 Ma ago.

(c) Grenville Province Uranium Deposits (A.D. Fowler and R. Doig)
(Concluding Report)

Uranium deposits associated with granitic rocks have occupied a small but significant role in Canada, and recent major discoveries of this type outside Canada are partly responsible for the current intense interest in potential new deposits within the Grenville Province. We have just concluded a comprehensive regional study of these deposits consisting of field examination, petrographic and geochemical studies and Rb-Sr isotopic work. Rb-Sr isotopic data from all significant occurrences from Bancroft, Ontario to the North Shore of the Gulf of St. Lawrence yield a uniformly youthful (950 Ma) age for the uranium bearing pegmatites and granites. Major and trace element data (including REE) support these conclusions, and along with petrographic evidence, show that the uranium mineralization is associated with late stage alteration of the pegmatites.

Comparisons with similar but more scanty data from the petrologically similar but economically very important Rossing deposit of Southwest Africa lead us tentatively to the conclusion that there are significant differences in the origin and economic potential of the deposits. Rather, we would suggest a closer parallel with the economically more tenuous Conway-type occurrences of New England.

5a. McMaster University - Department of Chemistry (C.E. Rees and H.G. Thode)

(a) Stable Isotope Studies

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

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

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

5b. McMaster University - Department of Geology (R.H. McNutt, L. Heaman, D.M. Shaw and G. Beakhouse)

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

The plutonic and gneissic units of the Chandos Township area, Ontario, give Rb/Sr whole rock ages of 1065 ± 12 Ma (.7035) and 1228 ± 22 Ma (.7031) for the Loon Lake monzonite and Tallon Lake gabbro-syenite sill respectively. The oldest unit in the area is the Apsley gneiss. The homogeneous, leucocratic parts produce a good isochron with an age of 1410 Ma (.7025). Thus, we have three distinctly different periods of activity in the area and one considerably older than previously known for this part of the Grenville province.

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

Plutonic and gneissic units of the southern part of the English River gneiss belt, Kenora-Redditt area, N.W. Ontario, have been dated by the Rb/Sr whole rock (at McMaster) and the zircon U/Pb method (ROM, Toronto, with T.E. Krogh). In general, zircon ages are older than Rb/Sr ages.

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

The metamorphosed basement rocks of the Pampean Range show considerable scatter on a Rb/Sr isochron diagram. However, they seem to indicate three periods of metamorphism at approximately 650, 465 and 425 Ma. Granitic rocks intruding the basement have ages of 475, 445 and 410 Ma. One batholith gives an age of 320 Ma supporting the idea of a Carboniferous event in this area.

6. Queen's University - Department of Geology (E. Farrar, D.A. Archibald and D.J. Kontak)

(a) Modifications to the analytical equipment (D.A.A., E.F.)

The amplifier of the MS 10 mass spectrometer has been replaced with a solid state data acquisition system. The system comprises an Operational Amplifier, a V.F.C., a Hewlett Packard Frequency Counter and a Commodore PET computer. This arrangement permits rapid data reduction.

(b) The Andes (D.J.K., E.F., D.A.A.)

Continuing from previous geochronological research in central and northern Chile, Bolivia and southern Peru we have initiated a study in southeastern Peru. Specifically we aim to establish the temporal relationships concerning the metallogenic and magmatic evolution of the Cordillera Carabaya.

(c) Antarctic Studies (E.F.)

Continuing from a previous geochronological study of plutons along the Lassiter Coast of the Antarctic Peninsula (with P.D. Rowley, U.S.G.S.), a study of similar intrusives along the Orville Coast has been initiated. Preliminary results indicate that these rocks were intruded during the same extensive Early Cretaceous magmatic event that has now been well documented for the Lassiter Coast.

(d) New Zealand (E.F.)

A literature review combined with new K-Ar dates (with C. Adams, D.S.I.R.) has permitted the time - space relationships of major alkalic

volcanic centers of South Island, New Zealand, and the Campbell Plateau to be established. The observed relationship has been ascribed to the overriding of the Indian-Antarctic ridge of the Pacific Plate.

(e) Canadian Cordillera (D.A.A., E.F.)

Kootenay Arc

A study of the geology and geochronology of the southern Kootenay Arc, B.C., is continuing. The study comprises conventional K-Ar dating as well as $^{40}\text{Ar}/^{39}\text{Ar}$ and U-Pb (with T. Krough, R.O.M.) zircon dating of selected plutons. This study has succeeded in elucidating the thermal and tectonic history of the Kootenay arc and surrounding areas.

Selwyn Mountains

A study of the K-Ar geochronology and petrography of the 20 intrusive bodies in the Selwyn Mountains, east of Cantung, has been initiated; this project is being undertaken in cooperation with K. Glover of Union Carbide.

(f) Korea (D.A.A., E.F.)

In cooperation with A.H. Clark, a K-Ar study of selected Sn and W mining districts in Korea has been initiated. Preliminary results suggest a complex thermal history for these areas; K-Ar mineral dates range from 80 Ma to 1700 Ma. $^{40}\text{Ar}/^{39}\text{Ar}$ age spectra will be completed in the near future.

(g) Kapuskasing Structural Zone, N. Ontario (D.A.A., E.F.)

A $^{40}\text{Ar}/^{39}\text{Ar}$ study (in cooperation with J. Percival, Queen's University) of the sheared eastern margin of the KSZ is in progress. A study of sheared and unsheared granitic rocks is about to begin in an attempt to resolve the time of brittle deformation.

7. University of Western Ontario (Department of Geophysics - A. Hayatsu, C.E. Waboso and H.C. Palmer)

(a) K-Ar isochron study of the Gettysburg Sill, Pennsylvania (A. Hayatsu and H.C. Palmer)

K-Ar and XRF analyses of samples from the sill are in progress. An isochron plot yielded two well defined isochrons which are parallel to each other. Each isochron seems to be composed of each of the two rock types (Rossville type and York Haven type) recognized by R.C. Smith (1973) based on chemical composition and mineralogy. The conventional ages of the presumably Rossville type samples are older than those of York Haven type whereas the field relation shows otherwise.

(b) The solubility of rare gases in silicate melts. (C.E. Waboso and A. Hayatsu)

The solubilities of neon, argon and krypton in basaltic andesite, alkali-olivine basalt and tholeiitic basalt melts have been measured as functions of temperature and pressure. The solubilities depend on the chemical composition of the melt, decrease with increasing atomic weight of the gas, increase with increasing temperature and pressure. Papers outlining the implications of these findings for K-Ar dating and for the outgassing of rare gases from the earth are in preparation.

8. University of Alberta - Department of Physics (G.L. Cumming, J. Gray, P. Thompson and S.J. Song)

(a) Instrumentation

We have begun construction of a new 5" radius, extended geometry, gas source mass spectrometer with a 5-fold multiple collection system for measuring Ar isotope ratios. The source and collectors have been built and work is in progress on the flight tube. This work is being carried out in cooperation with H. Baadsgaard of the Department of Geology.

We are also rebuilding one of our 12" radius instruments to incorporate the extended geometry configuration. The flight tube has a 9" radius, thus yielding an effective radius of 18" due to the extended geometry. We will be experimenting with a novel curved boundary magnetic sector in order to correct for spherical aberration of the magnetic focussing.

(b) Radiogenic Isotope Studies

(i) A major project is in progress studying the age and isotope relationships in the country-rock and ore zones of the Midwest Lake uranium deposit. This work is being done as a research contract from Exxon Production Research in cooperation with H. Baadsgaard of the Department of Geology. Over 50 Rb/Sr measurements have been made in order to establish age relationships in the host rocks and in the alteration products in the ore zone. Work is continuing and will be concentrating on U/Pb dating of the ore itself.

(ii) Further studies of U/Pb systematics in the Rabbit Lake uranium deposit have been essentially completed. This work is being carried out in cooperation with R. Morton and H. Baadsgaard of the Geology Department and J. Hovee of the Saskatchewan Research Council. The data essentially confirm and expand on previous work on the same deposit. Ore deposition took place in several stages between about 1300 and 1100 my ago. Subsequent remobilization occurred over a range of times extending up to the present.

(iii) Further work on Pb isotope ratios in the ores of the Thompson nickel belt has clarified our picture of ore emplacement and later alteration. We now see clear evidence for an initial ore forming event at 2320 \pm 30 my, followed by minor redistribution of Pb isotopes at 2015 \pm 15 my, 1620 \pm 25 my and 1125 \pm 60 my. The co-researcher on this project is O.R. Eckstrand of the Geological Survey of Canada.

(iv) A major isotopic study of the Pueblo Viejo gold deposit is now completed in cooperation with S.E. Kesler of the University of Michigan. U/Pb and Rb/Sr data on the country rocks and the sulphides of the ore body are all consistent with rock and ore formation at about 110 my. Some evidence exists for a possible metamorphic event at about 70 my.

(c) Stable Isotope Studies

(i) D/H studies of tree ring cellulose. An extensive four-year program of D/H analysis of trees grown in the Edmonton area is now approaching completion. Amongst the findings are a good correlation between D/H ratios and mean annual temperature, suggesting the cellulose in tree rings is storing meteoric-ground water hydrogen for up to 100 years without any exchange occurring.

(ii) Peat Studies. A program of detailed $^{18}O/^{16}O$ and D/H analysis of a peat core supplied by B.H. Luchman is now underway. Pollen analysis has been carried out on this core (Luckman) and it is hoped the isotope data will correlate well with the palynological data. The core covers a time period from the present to about 10,000 years B.P. (^{14}C dated).

(iii) Speleothem fluid inclusions. Work has begun on the simultaneous D/H and $^{18}O/^{16}O$ analysis of included water extracted from cave deposits (samples supplied by H.P. Schwarcz). It is hoped that simultaneous measurement of these ratios will allow a more precise interpretation of the $CaCO_3$ isotope ratios in terms of a temperature of deposition and hence yield unambiguous climate data for a time period up to 250,000 years B.P.

9. University of Toronto - Department of Physics, Geophysics Laboratory
(R.M. Farquhar)

During the past year, a number of lead isotopic analyses have been made on galena samples from the Central Metasedimentary Belt (CMSB) of the Grenville Province. These analyses add to the data bank for the Grenville already established by the work of Dr. I.R. Fletcher. The purpose of the analyses has been to attempt to establish two features which were not clear from Fletcher's research: 1) the extent of isotopic variations within given vein type Pb-Zn sulphide deposits, and 2) the variety of isotopic ratios which exist among galenas found in cavities in dolostones of the Niagara escarpment.

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VI METEOROLOGY AND ATMOSPHERIC SCIENCE

Compiled by: E.J. Truhlar

1. Introduction
2. The University of British Columbia
3. The University of Alberta
4. Alberta Environment
5. Research Council of Alberta
6. The University of Calgary
7. Western Research & Development
8. Saskatchewan Research Council
9. University of Windsor
10. McMaster University
11. University of Toronto
12. Ontario Ministry of the Environment
13. Acres Consulting Services Limited
14. Communications Research Centre
15. National Aeronautical Establishment
16. McGill University
17. Environnement Québec
18. Agriculture Canada
19. Canadian Forestry Service
20. Atmospheric Environment Service
21. Bibliography

1. Introduction

Research in Meteorology and Atmospheric Science continues at a high level, but primary concerns are focussed on the environmental effects of air pollutants and the socio-economic effects of climate. The long-range transport of air pollutants is a serious problem, especially the impact of acid rain on the biota in the numerous lakes of the Canadian Shield. A joint Canada-U.S. program to protect the transboundary flow of pollution has not been settled, but depends on the policies of the new U.S. Administration during 1981 and succeeding years.

A series of Workshops and meetings were held across Canada to find out: the effects of climate on various sectors of society, the economy and the environment; the extent to which climate services are being used; deficiencies in services and information available; and the comprehensive requirements of each sector. Sectors examined were agriculture, construction, fisheries and oceans, forestry, recreation and tourism, transportation and water.

The Canadian Meteorological and Oceanographic Society broadened its international and national activities and responsibilities. All six members of the newly formed NRC Canadian National Committee for the World Climate Research Program are CMOS members including the President (ex officio). This Program and Committee are essentially successors to GARP and its scientific committee.

The Society held its 14th Annual Congress in Toronto, May 22-27, 1980, together with the American Geophysical Union Spring Meeting. The scientific program of the Congress was integrated with that of the Meteorology and Oceanography Sections of the AGU into a combined scientific program. This was a unique occasion, being the AGU's first annual meeting outside the United States and the first to be held jointly with other societies. Co-hosts with the CMOS were the Canadian Geophysical Union, the Division of Aeronomy and Space Physics of the Canadian Association of Physicists (CAP) and the Canadian Society of Exploration Geophysicists.

CMOS Council approved establishment of a permanent national office, initially sharing facilities with the CAP in Ottawa.

The Society prizes for 1979 were awarded to: Yves Delage and Claude Girard, Dr. Andrew Thomson Prize in Applied Meteorology; Eduardo Freire and William G. Large, Graduate Student Prizes; David B. Fraser, The Rube Hornstein Prize in Operational Meteorology. Citations were also awarded to: Kenneth C. Curran Regional Director, Maritime Region, Canadian Coast Guard for his outstanding contribution in helping to alleviate a specific environmental pollution problem--the Kurdistan oil spill which occurred in March 1979; La Société Linnéenne de Québec, for its notable contribution to conservation of the natural environment and to popular education concerning environmental ethics.

2. The University of British Columbia - Department of Geography

(a) Determining the Mesoscale Variability of Solar Radiation (J. Hay)

Observations of solar radiation in a 12-station network in and adjacent to Vancouver have indicated substantial variability in the distribution of solar radiation. These data are being used to develop and verify numerical models that use geosynchronous satellite data to estimate solar radiation at the earth's surface.

(b) Continuing Studies (J. Hay/J. Knox)

Studies of the short-wave irradiance for inclined surfaces and of the anomalies in the 50-kPa geopotential height patterns are continuing (see CGB, 1979).

(c) Urban/Coastal Boundary-Layer Structure (T. Oke)

Analysis of the summertime boundary-layer structure in Vancouver continues. The study is based on a comprehensive data set gathered in Vancouver during 1978 using a 30-m instrumented tower, minisonde balloon flights and an acoustic radar. Interest is centred on the structure of the mixed layer, its relationship to the surface layer conditions and interaction with the land-sea breeze circulation.

(d) Rural/Suburban Evapotranspiration Comparison (T. Oke)

Bowen ratios -- energy balance measurements in Vancouver and its environs during the summer of 1980 -- are being analysed to investigate any evapotranspiration differences caused by urbanization. The suburban measurements are also being related to residential water-use records.

(e) Radiative Flux Divergence in Urban Canyons (T. Oke)

A special apparatus for measuring three-dimensional radiative flux divergence has been constructed and tested. It is being used to study the role of radiation in air temperature change at night in different urban canyon geometries.

3. The University of Alberta - Meteorology Division, Department of Geography and Institute of Earth and Planetary Physics

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

An airfoil icing model has been developed that computes the streamlines about an arbitrary two-dimensional airfoil, determines cloud droplet trajectories using a complete equation of motion, and predicts as a function of time the amount and extent of icing that will occur on the airfoil under conditions in which the droplets freeze where they impinge. The model has been tested against other available experimental and theoretical results and has been found to yield useful estimates of ice accretion under "dry" conditions (without runback).

(b) Dry Ice Sublimation (E.P. Lozowski and B. Kochtubajda)

Theoretical and experimental work on the simulation of dry ice sublimation in clear air and clouds has yielded results that will be useful in optimizing the logistics of dry ice seeding in cumulus clouds.

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

A comparison of finite-element and spectral solutions to the equations governing the flow in a spectrally-truncated, two-layer, baroclinic channel model has shown that the finite-element method performs well in general, but that spurious boundary waves introduced by the finite-element boundary conditions can amplify and propagate so as to severely contaminate the forecast under strongly developing conditions.

(d) Thermodynamics of Icing Sprays (E.P. Lozowski and H. Auld)

A study of the dynamics and thermodynamics of icing sprays injected into an icing tunnel has been completed. Using the theoretical model developed, it is possible to predict the extent to which the spray is out of equilibrium with the airstream when it arrives at the working section of the tunnel.

(e) Industrial Fog Cloud and Precipitation During Cold Weather (R.B. Charlton and C. Park)

Field studies of cooling tower plumes and their precipitation are being conducted in Edmonton's petrochemical area during the coldest days of winter. The results are applicable to environmental studies of oil sands extraction plants and to development of petrochemical industries at Arctic locations.

(f) Urban Air Pollution (K.D. Hage)

Ten new field experiments involving simultaneous profile measurements of wind, temperature, and carbon monoxide were completed at three locations in the North Saskatchewan River valley in Edmonton during 1980. At one location, in particular, standing internal buoyancy waves were observed on at least two occasions. These waves resulted in major local fluctuations in carbon monoxide concentrations from a nearby slope (ravine) source.

R. Wong has completed specifications for a numerical simulation of the airflow and pollutant dispersion in the river valley. He is using terrain-following coordinates with variable vertical grid intervals.

R. Rudolph applied the particle-in-cell (PIC) technique to simulate dispersion in a two-dimensional valley containing a single line source (roadway) oriented along the valley axis near the base of one slope. He used a specified double-vortex wind field with slope drainage wind speeds comparable to those observed in Edmonton. The time scale of the resulting buildup of concentrations at an upslope station was comparable to that observed in locations with along-valley sources.

K. Johnstone applied two different Markov chain models to daily precipitation data from Beaverlodge, Edmonton, and Medicine Hat. The models successfully estimated the number of wet days in a month and the total monthly precipitation, but failed to reproduce adequately the frequency distributions of maximum daily precipitation in independent samples.

(g) Destructive Windstorms (K.D. Hage)

Collection of data on destructive Alberta windstorms has been completed, except for minor details, and was extended to include Saskatchewan. This extension was deemed necessary as a basis for studying variations in storm type, and for mapping type frequencies.

(h) Synoptic-Scale Studies (E.R. Reinelt)

Four different projects were completed during the past year, and two new investigations started. Procedures for analysing and interpreting satellite data were refined and updated to meet the needs of current research in the High Arctic and Western Canada.

B. Greaves, using data from NOAA-5, investigated coastal circulation patterns on Banks Island and the Beaufort Sea. Good evidence for the development of sea-breeze circulations was deduced from the behaviour of thermal gradients along the western shore of Banks Island, and from the formation and motion of cloud within 50 mi. of the coastline.

M. Dupilka has used a simple dipole model to investigate the origin and generation of "mountain-associated waves". Based on the theory of airflow around cylinders, the model has been extended to serve on a synoptic scale. In this "natural" model the cylinder has been replaced by the massif of a mountain. The natural dipole appears to offer a plausible explanation in over 50 percent of the cases studied. The observed events were found to have preferred azimuthal ranges closely coincident, in most cases, with the locations of major peaks in the Rocky Mountains.

J. Wieler has undertaken a study of convective storms in Alberta, making combined use of satellite and radar data. He will attempt to determine the motion of convective cells in relation to tropospheric winds, and deduce a stability index from cloud-top temperatures.

D. Phillips is developing a realistic model to simulate cyclogenesis in the lee of the Rocky Mountains.

E. Reinelt became involved in the problems besetting the verification of operational cloud seeding in North Dakota. Using data provided by the pilots of commercial seeding planes, AgI-injected air parcels were tracked for some hours downstream, beyond the time of release. Knowing the trajectories of the seeded volumes of air, it was a fairly simple matter to correlate the "labelled" volumes with the contents of the rain gauges over which they passed. The results of this method, though not conclusive proof of the efficacy of cloud seeding, show promise for dealing objectively with conflicting claims.

4. Alberta Environment

A major study into methods for measuring the dry deposition of gaseous SO₂ was initiated. A workshop was held in November to discuss the characterization of techniques. Other projects included a sulphur isotope study in the Peace River country, a selenium measurement program in the Pincher Creek area, an examination of the fate of silver iodide in central Alberta, and an extension of earlier urban valley pollution studies in Edmonton. A survey of intermittent control systems was completed documenting their advantages or disadvantages, operating characteristics and applicability to Alberta industry. The Calgary tall tower was re-instrumented to record wind and temperature data at two levels including hourly averages of wind speed and direction, temperature and temperature difference, as well as the standard deviations of the azimuth angle and wind speed. The Edmonton tall

tower was closed in favour of a short tower at the air pollution meteorological station south of the city.

The Alberta Oil Sands Environmental Research Program, now part of the Research Management Division of Alberta Environment, has completed the first five years of its ten-year period of operation. Directed research continues to provide information that will permit the orderly development of the oil sands without undue environmental damage.

The baseline state of the AOSERP Study Area is being monitored by a meteorological data collection network with supplementary profile information collected during shorter predetermined study intervals. Research emphasis shifted very slightly during 1980 toward further investigation of various modelling activities. Several scientific reports relating to meteorology and air quality were published by the Program in 1980.

Acid forming emissions and their transport and effects on the ecosystems in Alberta have been identified as a high priority research area for the Department. Research reviews on sulphur oxides and nitrogen oxides were completed.

5. Research Council of Alberta - Atmospheric Sciences Department

(a) Introduction

The Alberta Hail Project's five-year weather modification program concluded in 1979. This project, which was managed by the Alberta Weather Modification Board, was the primary area of research activity for the Atmospheric Sciences Department. Since April 1, 1980 the Alberta Research Council assumed full responsibility for administration of the cloud-seeding operations as well as the research endeavours of the Alberta Hail Project. As a result, 1980 was a year of planning for the future. However, some research activities continued during this interim year (see 1979 Canadian Geophysical Bulletin for background information) while new areas of research were initiated for clients other than the Alberta Department of Agriculture.

(b) Meteorological Services

The major activity of the weather forecasting group was the operation of the meteorological and forecast services and upper-air sounding programs for the 1980 cloud-seeding program. In this regard, efforts are continually being made to improve the forecasting accuracy. Recent research has led to development of a synoptic and mesoscale based index of convection. Although these forecasts are 80% or more accurate and operationally very useful, they are not yet suitable for use as an aid in evaluating cloud-seeding effects.

(c) Storm Environment

The Rocky Mountain House Area Genesis Study (RAGS) was continued during 1980 with a major field program successfully carried out in July. In addition to the standard meteorological parameters measured in the past, the 1980 field program included research flights to map the total heat content (equivalent potential temperature) of the atmosphere in the subcloud layer.

(d) Cloud Physics and Modelling

As part of the continuing research program in cloud physics and modelling a one-dimensional, adiabatic plume model, to describe the evolution of cloud drop spectra by means of nucleation, condensation, and

coalescence, has been developed and further extended to a two-dimensional warm cloud model, which is now producing reasonably realistic results.

The effect of artificial ice nucleants on precipitation processes was studied through controlled seeding experiments on cumulus clouds. Results showed that some clouds that do not naturally produce rain can be made to precipitate by seeding with artificial ice nucleants. Because dry ice may be a suitable seeding agent for hailstorms, a numerical model has been developed to investigate the sublimation rate of dry ice in clear air and simulated cloud, and has been tested against wind-tunnel experiments.

The structural analysis of hailstones that were collected during the 1978 and 1979 field seasons suggests that the coalescence process (drop embryo) and the ice process (graupe embryo) are active in Alberta hailstorms but observed in different regions of the hailswath.

(e) Gas Effects on Precipitation

For quite some time, considerable interest has been shown in the possibility that emissions from gas plants could be affecting the precipitation processes in Central Alberta, specifically that gas plant emissions could be responsible for the apparent decrease in damaging hailfall in the southern project area of the Alberta Hail Project.

A rigorous statistical analysis has been performed on the relation between hail insurance data and gas plant emissions. A statistically significant correlation between yearly crop loss/risk and total sulphur emissions has been found in much of the project area. Specifically, in the area's southwest quadrant where most of the gas plants are located, a correlation of -0.8 was found between loss/risk and daily total sulphur emissions, significant at better than the 1% level.

(f) Statistical Evaluation

The evaluation studies of the previous five-year project identified several immediate problems that must be solved. Covariates are needed to reduce sample size requirements and to indicate cloud-seeding effects when no randomization is implemented.

A mathematical integration technique has now been developed and will be applied to previous Alberta data for the study of covariates.

In an effort to study the properties and usefulness of crop hail insurance data for cloud-seeding evaluation, township by township insurance data were gathered for both Saskatchewan and Alberta from 1938 to 1979 as well as climatic data for both provinces through the historical period.

The collection of evaluation techniques and the development of computing programs for their application was continued.

(g) Weather Radar Studies

Analysis of data obtained with the 10-cm polarization diversity radar and the 5-cm weather radar at the Alberta Hail Project field site demonstrated the feasibility of combining polarization and dual wavelength techniques to provide improved measurements of precipitation.

Continuing work with Alberta Environment resulted in the evaluation of various radar facilities throughout the world for the purpose of developing a facility in Alberta for use by operational hydrologists. The preliminary design of a weather radar data transmission system has

been completed. This system is intended for use by the Alberta River Forecast Centre (Alberta Environment) for stream flow forecasting, that is, weather radar data will be transmitted from the Alberta Hail Project field site to Edmonton for operational application.

Point-by-point comparisons of surface observations of rain and hail with radar observations taken during 1979 are being carried out. This work is directed toward corroborating earlier results that suggested quantitatively the probability of occurrence of various precipitation types and intensities as a function of the "equivalent radar reflectivity factor".

During the past 5 years considerable effort has been devoted to development of a facility for archiving and analysing digital radar data. The Fundacao Educacional de Bauru in Brazil expressed an interest in this system; consequently one was built and sold to them. The hardware for the radar-to-computer interface was built by the Athabasca Research Corp. Ltd. (ARCL) for the Research Council. This technology has now been transferred to ARCL so that the system can be made available commercially.

(h) Hailfall and Rainfall Studies

The density of surface networks of hail-measuring instruments required to accurately measure the intensity of hailfall was studied and determined. Data from such networks have helped identify the radar echo. The maximum intensities in hailfalls ("hail cores") were found to occur about 10 km apart.

(i) Computing Systems

Software and hardware enhancements were made to the computer that records weather radar data at the Alberta Hail Project field site. The hardware changes allowed the computer to cope with increasing demands while the software changes improved multiuser access to the data in real-time.

Work is underway to make a recently developed graphics subroutine package compatible with international standards, thereby allowing programs and programmers to be interchanged more easily.

6. The University of Calgary - Department of Physics

Visibility and Pollution:

Through the use of telephotometers and nephelometers, the visual quality of air in the Calgary region is being investigated. Visibility is related to aerosol size distribution and concentration during periods of temperature inversion and Chinook phenomena.

Lidar Probing of the Lower Atmosphere:

A simple ruby lidar is being developed to make remote measurements of particle concentrations within the boundary layer. This instrument will be used in conjunction with the Acoustic Sounder already operational within the Atmospheric Physics Group.

Hemispherical Sky Radiation Measurements:

A 220° field of view visible photometer is being developed which makes use of the CCD arrays now available. Rapid measurements of monochromatic visible radiation (downward) flux will yield spectral radiances and estimates of earth (spectral) albedo that should be useful

to solar energy technologists. A pyroelectric detector and rotating mirror system is used to measure the sky radiance in both the visible and infrared regions, and in combination with the photometer gives a complete description of regional electromagnetic energy flux.

Acoustic Remote Sensing:

A Doppler acoustic sounder capable of measuring wind profiles and turbulence profiles has been built and operated during winter months. The development of several Chinooks has been observed with this. Very strong wind shears were found to occur at these times.

7. Western Research & Development

Western Research & Development continued to supply meteorological consulting services to industries and governments. Many projects dealt with stack design, urban air pollution, cooling-pond fog evaluations and climatological variables. Major projects concerned observations of plume rise from flare stacks, evaluation of NO to NO₂ conversion in plumes originating from large turbine-driven compressors, derivation of wind climatologies for the Alberta Oil Sands area and testing of diffusion models. The last two projects were conducted for the Research Management Division of Alberta Environment in association with Intera Environmental Consultants Limited.

8. Saskatchewan Research Council

A major undertaking in 1980 was a preliminary overview of the acid precipitation situation in northern Saskatchewan and northeastern Alberta. Its basic purpose was to estimate regional emissions to the year 2000, including their transmission and likely deposition patterns within this area, to determine potential susceptibility of the whole region, and to identify particularly sensitive areas or local conditions within it. The results from this survey are to be used to design an air, precipitation, water, soil and biota monitoring system that, by concentrating on the appropriate sites and ecosystem components, would be capable of most readily identifying future changes and their causes.

Preliminary findings show that, despite emissions of SO₂ from the two tar sand plants now in operation, and from other regional sources there is as yet no discernible increase in the acidification of precipitation above global background. The preliminary phase of a report is due for completion early in 1981.

Potash dust sampling continued to be an area of activity, with the design of a specific stack sampling program that was put forth as a standard system for emission control purposes. The interaction of potash dust fertilizers and alkaline soils with rain via washout of airborne particles of these materials gives rise to a near reverse situation from acid rain, viz. pseudo-alkaline precipitation with pH's of 6.5 to 7.0. Studies have been initiated on the transition zone situation between these two regimes.

Modelling of open-pit uranium mines as sources for radon gas emission to the environment continued, and most research has centred on control of such emissions within mining equipment. In particular the subsequent behaviour of radon daughter-products in the working environment and under downwind air movement is of concern.

The thunderstorm climatology of northern Saskatchewan was investigated to discover any readily recognizable characteristics that would distinguish between high and low rainfall-producing storms. Predictions of forest fire outbreaks depend on the identification of these "wet" and "dry" lightning situations. Preliminary results suggest that present electric field detectors will not provide this information, unless combined with radar.

SRC commenced a program of hydrometeorological data re-transmission in 1980, and three stations are being operated for specific clients. Research is being conducted into the interfacing of standard meteorological sensors to these sites as well, to achieve complete remote operation.

9. University of Windsor - Department of Geography

The Essex region precipitation network is in its 11th year of operation and continues to be funded by the Essex Region Conservation Authority (M. Sanderson).

Palaeoenvironmental studies are being carried out in southern Baffin Island, N.W.T. (J. Jacobs).

10. McMaster University - Department of Geography

Evaporation from vegetated surfaces. This project has been completed. Three papers are in press and a final one is in preparation.

Testing of solar radiation models. This project, an extension of a previous one to examine the performance of models to estimate solar radiation, has studied the effect of using cloud opacities instead of amounts and the importance of considering aerosols in some urban environments. The final report is to be published by the AES.

The effects of pollutants on infrared radiation. An initial attempt has been made to collect infrared data from a suburban and an industrial site in Hamilton in 1980. This work will be continued and combined with the use of numerical models.

Aerosol effects on solar radiation. Ten years of cloudless sky radiation data for Canadian stations are being analysed to estimate variations in bulk optical depths and single scattering albedos for aerosols.

11. University of Toronto

Department of Physics (Meteorology)

(a) Cloud Physics

The study of the urban boundary layer with an acoustic Doppler sounder was terminated after a final publication on its structure. This indicated for the first time that there are no structural differences above a certain roughness height when compared to the B.L. over a flat terrain.

The warm rain studies consisted of: (i) experiments on the size spectrum of breakup fragments after collisions of raindrops, indicating pressure dependence in the range between laboratory pressure and 50 kPa; and (ii) numerical calculations on the drop spectra evolution in a 2-km high rain shaft, using the most up-to-date experimental data, showing that Marshall-Palmer distributions are not maintained and no equilibrium distributions were reached after a certain distance of fall.

Icing experiments confirmed the importance of shedding and the characteristics (temperature, phases) of the shed water substances.

The Cloud Physics Group also actively participated in the Precipitation Experiment (PEP) of the World Meteorological Organization, at the field site in Spain through the scientific leadership of Prof. R. List (who proposed the experiment in the first place) and through the endeavours of one of the students. (Weather Modification in WMO has a budget of about \$0.5M for management and coordination.)

(b) Ion Studies

Ion-induced heteromolecular nucleation in the gas phase is being studied. Two different mechanisms have been found active. In one of these ions attach molecules of reactants and each particle of the product grows around an ion; a typical case is ammonium chloride produced from hydrogen chloride and ammonia. In the other mechanism the reaction occurs at the periphery of hydrate cluster ions, the product separates from the ion and the nucleation occurs in the gas phase, from neutral molecules; one example is sulfur dioxide oxidation. The study is being continued, with two complementary techniques: obtention of nucleation curves (rate of nucleation as a function of reactants concentration) and mass spectrometry of the initial stages of nucleation.

(c) Atmospheric Waves

Current work on internal waves is concerned with stationary disturbances forced by flow over mountains, and the evolution of trapped waves originating in parallel shear instability. In the former case interest had been motivated by a desire to understand the dynamics of intense downslope wind storms while current work is directed toward involvement in the ALPEX experiment. In the latter case efforts are principally directed toward understanding in detail the turbulence transition in stratified parallel flows. This work has involved investigation of the linear stability of the finite amplitude limit cycle into which two-dimensional Kelvin-Helmholtz billows evolve. It appears that the turbulence is triggered by a shear-aligned convective instability.

Two projects have been initiated that are aimed at understanding phenomena in which planetary-scale Rossby waves are of paramount importance. The first of these concerns the mechanism of sudden-warming; a Matsuno-like model of this process has been successfully constructed and employed to investigate the cause of the double layer structure of the wavenumber one warming that had been obtained in previous investigations.

Studies are being conducted by C. Lin on scale interactions of atmospheric waves involving: (i) baroclinic waves in the meridional direction, to determine their meridional scale; (ii) the zonal scale selection mechanism of planetary waves in the presence of baroclinic and orographic instabilities.

(d) Climatic Change

The gravitationally self-consistent model for post-glacial sea-level variations has been employed successfully to retrieve the mantle viscosity profile, and a "best" reconstruction of the disintegration of the major ice sheets that occurred at the end of the last glacial epoch beginning 18,000 years ago. This reconstruction of the ice sheet chronology has a maximum Laurentide thickness of about 2500 m which is considerably less (by about a factor of 2) than that of the reconstruction preferred by members of the CLIMAP project. These data and new information on sea-surface temperature anomalies are being employed as boundary conditions in a general circulation model simulation of the climate during the Wisconsin maximum. This work is being carried out simultaneously with efforts to construct a new model of the glaciation-deglaciation process itself.

(e) Convective Processes

Dynamic interactions between convective clouds and large-scale weather processes are studied from both theoretical and observational points of view. Current research projects include: (1) diagnostic determination of cumulus effects on the synoptic momentum fields in the tropics, using GATE data; and (2) contribution of cumulus convection to the rapid intensification of mid-latitude weather systems.

(f) Forest Fires

Projects reported in the 1979 Canadian Geophysical Bulletin are continuing.

(g) Infrared Fluxes at the Surface

A design study has also been made of a small instrument to measure the atmospheric flux at ground level in the 8-13 μm atmospheric "window" region as a function of angle and wavelength. The objective of this research is to investigate the radiative cooling available in this region under typical atmospheric conditions. The results would then be applicable to the thermal design of buildings for the Canadian climate.

(h) Upper Atmosphere Composition

The composition of the middle atmosphere is being studied by J.R. Drummond using data from the Stratospheric and Mesospheric Sounder (SAMS) instrument on the Nimbus 7 satellite. Water vapour is monitored by means of thermal emission in the rotation band and fluorescence in the 2.7- μm band. Attention is concentrated on the upper stratosphere and mesosphere. This is a co-operative effort with University of Oxford.

A laboratory experiment has been started to investigate the instrument parameters required to monitor formaldehyde in the stratosphere using balloon instrument and the "pressure modulation" techniques employed in the spacecraft instrument. Formaldehyde is an important intermediary in the decomposition of methane in the upper atmosphere leading to the production of carbon dioxide and water. It is hoped that this work will lead to the construction of a balloon instrument to measure simultaneously the concentrations of several stratospheric minor constituents. The principal difficulty will be in achieving sufficient sensitivity since the concentration of formaldehyde is expected to be 10^{-10} v/v.

Institute for Environmental Studies

The Institute for Environmental Studies undertakes interdisciplinary environmental research studies, many of which have an atmospheric component with respect to acid rain, climate change, risk assessment and environmental monitoring.

Professor F.K. Hare ended his 5-year term as Director of the Institute, and became Provost of Trinity College. However, Dr. Hare retains his membership and a research interest in the Institute.

Professor Ian Burton (the new Director), Dr. A. Whyte and Dr. R.E. Munn are pursuing their studies of the socioeconomic impacts of climate change and variability. Finally, the work on characterizing indoor-outdoor air pollution exposures is continuing, jointly with the Gage Research Institute and the McMaster Medical Sciences Group.

Dr. Munn has recently been awarded a substantial research grant, jointly with Prof. G. Likens of Cornell University, to analyse the precipitation chemical climatology of Hubbard Brook, New Hampshire.

12. Ontario Ministry of the Environment - Air Resources Branch

(a) Air Quality and Meteorology Section

The physical concepts underlying the measurement and modelling of pollutant concentrations resulting from point sources have been examined. A technique to estimate the deviation of observed concentrations from predicted ensemble averages has been developed.

A model for dispersion of pollutants emitted from an elevated source into a convective boundary layer has been developed. Some of the most recent information about dispersion in the mixed layer has been incorporated in the model.

A statistical model has been developed to estimate long-term concentrations of pollutants associated with long-range transport. Dispersion and removal of pollutants are described in terms of statistics of their physical processes. The model has been used to estimate wet deposition of sulphur over a grid covering Northeastern United States and Canada.

(b) Special Studies Unit

A special study, under contract to Moniteq Ltd., was carried out in the Nanticoke area to investigate the location and intensity of fumigation from the plume of the Hydro generating station stacks, under the influence of a thermal internal boundary layer.

A network of precipitation samplers was commissioned across the Province of Ontario, to study the wet and dry deposition of acids, as well as a number of ions and trace metals. Some samples are also being collected on an event basis, to yield information on the frequency and intensities of acidic deposition episodes, as well as their associated air masses of origin.

A study of precipitation washout from plumes at the Sudbury INCO smelter and Nanticoke Hydro generating station was carried out, under contract to Ontario Research Foundation.

13. Acres Consulting Services Limited

A quantity/location and emission/discharge inventory of 15 chlorinated and aromatic hydrocarbons was completed for a study commissioned by the Ontario Ministry of the Environment. Data on total emissions of the hydrocarbons were estimated for major Ontario cities.

14. Communications Research Centre

The project dealing with the study of climate in Canada and its influence on radiowave propagation (outlined in the 1978 Bulletin) continued through 1980. Effort during the year concentrated on more detailed analyses of the data from tipping bucket rainfall recording stations across Canada.

The form of the rainfall rate distribution - of some concern in microwave attenuation modelling - was examined with particular emphasis on the applicability of the log-normal, the gamma, and the power-law forms. The seasonal variation in precipitation intensity statistics and the climatological nature of this variation were investigated for selected locations across Canada.

Results of this work have been submitted to and incorporated in the technical reports of the International Radio Consultative Committee.

15. National Aeronautical Establishment - Flight Research Laboratory

Again in 1980, the National Aeronautical Establishment and the Atmospheric Environment Service participated in the High Plains Cooperative Experiment (HIPLEX) at Miles City, Mont. The annual 3-month experiment investigates the precipitation formation process and seeding potential of convective clouds over the plains. The NAE Twin Otter and 12 scientific and support staff participated in this experiment from May 25 to June 26, 1980. Further details are as reported in the 1979 Canadian Geophysical Bulletin. Data collected by the Otter during HIPLEX 1979 were analysed further.

At the request of the Department of Agriculture, the Flight Research Laboratory undertook a series of flight experiments to measure the flux of CO₂ in the boundary layer above several types of vegetation. The NAE Twin Otter aircraft, fully instrumented to measure air motion, was fitted with two CO₂ sensors provided by the Department of Agriculture. One was a Barringer CO₂ Ambient Gaspec; the other, an Open Path CO₂ Analyzer specially built by the Department of Agriculture. Each was flown for approximately half the experiment which consisted of 9 flights in the Ottawa area during August and September.

16. McGill University - Department of Meteorology

During 1980 research proceeded in the general areas of large-scale atmospheric dynamics, numerical weather prediction, cloud and precipitation physics, radar and satellite meteorology, radiative transfer, physical climatology, and surface energy budget.

An analysis was completed of the average errors of an ensemble of ten-day forecasts made with a global model at the European Centre for Medium Range Weather Forecasts. The error pattern was found to be "equivalent barotropic" and characterized by a spurious decay in the model of zonal wave number two.

The structure of steady forced planetary waves was investigated by means of a linearized quasi-geostrophic model in spherical geometry. Emphasis was on the effects of vertical resolution and the upper boundary condition in the model. Work continued on modelling planetary waves with a time-dependent nonlinear Beta-plane model.

The forecast model of the Atmospheric Environment Service was adapted for investigation of forced planetary waves to determine the effects of vertical resolution on wave structure, both for small amplitude waves (as in linear models) and for larger, more typical amplitudes.

In the area of precipitation physics considerable progress was made. A fast-running, two-cylinder model of cumulus clouds was developed, in which the microphysical, dynamical, and thermodynamic properties have been simulated and compared with results from a more extensive two-dimensional model. Research in three-dimensional numerical simulation has also continued. The behaviour of a large sample of radar rain echoes on Day 261 of GATE was analysed and found to agree satisfactorily with model simulations. The effects of wind shear and separation distance between clouds were subjects of special study.

Simulation of a cloud field using random heat and moisture conditions at the ground was completed. Results disclosed such features as the suppression of small clouds, the successive generation of clouds, the interactions of clouds with the boundary layer and environment, and the interaction of downdraft circulations.

Effects of silver-iodide seeding on cloud behaviour were examined using a two-dimensional model. Extension to three dimensions is underway.

A method of parameterizing hail is being developed so that the cloud models can be applied to studies of air flow and precipitation processes in Alberta hailstorms.

A numerical model of the evolution of rain drop size distributions below cloud base has been developed; model calculations are being compared to observed drop size distributions from HIPLEX.

Research continued on the influence of rain on earth-to-space propagation at centimetre wavelengths. Using radar data from one summer, statistics were generated for the differential attenuation on pairs of paths to adjacent geosynchronous satellites. The same data were used in compiling average vertical profiles of the radar reflectivity of rain, for application to scatter interference problems.

Modelling studies on the transfer of solar radiation through hazy atmospheres, with particular emphasis on "arctic haze" have been completed. A highly parameterized solar radiation model has also been developed and shows promise for use in large-scale dynamical models.

The McGill energy budget models are being extended and modified to be particularly applicable to studies of climate-vegetation interactions. This would be useful in climate impact studies dealing with the consequences of deforestation, flooding, unusual wet or dry spells, and various other man-made and natural changes of the environment.

17. Environnement - Québec - Service de la Météorologie

La plupart des études décrites dans le B.C.G. en 1979 ont été poursuivies en 1980; mentionnons en particulier:

- (a) Etude de rationalisation des réseaux météorologiques du Québec.
- (b) Programme de Connaissances intégrées: bassins des rivières L'Assomption et Du Nord.
- (c) Programmes en énergie solaire et éolienne.
- (d) Programme de validation et de mise en banque des données transmises en temps quasi réel via le satellite GOES.
- (e) Programme d'extraction et de traitement automatique de divers types de diagrammes.
- (f) Etude micrométéorologique du climat urbain de la région de Québec.
- (g) Inventaire en vue de la fusion éventuelle de deux banques de données mensuelles.
- (h) Prévisions hydrométéorologiques en période de fonte.

Quelques projets nouveaux ont aussi été mis en marche, à savoir:

- (i) Transport à grande distance des polluants atmosphériques en relation avec les pluies acidifiées:

Le Service de la Météorologie est impliqué dans les aspects concernant le transport et la diffusion des polluants atmosphériques en l'occurrence les oxydes de soufre et d'azote. En 1980, on a procédé à une détermination préliminaire des zones particulièrement affectées et à une analyse en profondeur des divers modèles existants.

(j) Climatologie du parc Forillon:

Des mesures de température et de précipitation ayant été effectuées sur le territoire du parc Forillon en Gaspésie durant cinq ans, on a commencé une analyse des données en vue de produire une étude climatologique de cette région.

18. Agriculture Canada - Agrometeorology Section, Ottawa

The broad objective of the Agrometeorology Section is to develop improved methodology for assessing agroclimatic resources and for analyzing and monitoring crop response to weather, soil and land management in order to provide agrometeorological information for agricultural research and services and for planning, marketing and farm management decision-making.

Activities fall into three main areas of interest:

(a) Crop-Weather Analysis

This area is dedicated to development of a crop-environmental data acquisition and analytical processing system for analysing selected biophysical plant-weather relationships. Studies included the following:

(i) The exchange of CO₂ and water vapour above a corn crop with the adjacent atmosphere was measured using the eddy-correlation technique in the development of a system to evaluate absorption of CO₂ and transpiration of water for a crop. Measurements were made successfully on-site for small areas and on board an aircraft for larger areas. Supplementary observations of leaf area index, yield, temperature, soil, moisture and biomass were made to evaluate growth rate and growing conditions. A model for estimating plant transpiration was developed for analysis of the field measurements.

(ii) A spectral radiation instrument and a data processing system were used together to obtain rapid measurements of leaf area index for several crops at varying densities. A laboratory version of a microprocessor-based system for measuring soil moisture was completed.

(iii) Water extraction patterns were obtained under several soil textures and environmental growing conditions for testing and evapotranspiration model, to clarify changes in leaf water potential relative to various atmospheric and soil water conditions.

(iv) Results of several years' spectroscopic analyses showed that bandwidths should be selected relative to patterns in crop spectra that are associated with specific physiological features to obtain the information needed on crop growth and development, and growing conditions. Data from a narrow two-band airborne system, sensitive to chlorophyll absorption, were obtained under a contract with the University of Manitoba.

(b) Crop Information and Agroclimatic Assessment

In this area one group is developing a methodology for determining spatial distribution of crops, growing conditions and agroclimatic resources from plant-weather relationships that are based on biophysical, spectroscopic and statistical principles. Data will provide information for more efficient production and marketing of Canadian crops. Studies include:

(i) Generation I (William's Model) was tested in the operational mode during the year to provide weekly yield estimates, May 1 to

July 31, for each crop district in Western Canada. Yield estimates were terminated by mid-summer for the Russian crop regions.

(ii) A field study involving radar imagery analyses was successfully established and imagery for one date in July was obtained. Analyses of the radar data for the Guelph test site were presented in a University of Guelph report.

(iii) A report is being prepared on the evaluation of current procedures for estimating soil temperature and frost. Several analyses of proven data were required for this evaluation.

(iv) A draft manuscript "Soil-water models. A Review" has been prepared, accompanied by recommendations on the appropriate application of each model. A bulletin is being drafted on computer simulation model of soil water movement and uptake.

(v) Adaption of the FAO model to crops other than spring cereals was initiated; evaluation of the model was commenced but is now in abeyance because of transfer to RDIA Branch.

(c) Agrometeorological Applications and Service

The goal of this is to develop interpretative techniques for agrometeorological applications at a farm management level and to maintain operational agroclimatic data systems in support of research and services. Activities included:

(i) Soil Moisture Evaluation Project (SMEP) prepared 22 weekly reports on plant available water for each crop district in Western Canada during the growing season. Reports were distributed within 48 hours to 65 user agencies across Canada.

(ii) Two Agromet Section Technical Bulletins: on determining field work days in Canada (No. 92); and on weather risk in harvesting hay (No. 91).

(iii) Documentation of the Versatile Moisture Budget was completed and a scientific paper published (Can. Agr. Eng. 22). The method was not modified owing to resignation of a staff member.

(iv) Documentation of the microprocessor system for recording Agmet weather data was not completed. Further assessment of instrumentation needed must be made.

(v) Information was provided to other agencies through 11 reports in "Weather and Agriculture - Canada, 1980" for Agriculture Canada executives, 10 reports on soil water conditions in Western Canada, 22 SMEP Reports, 75 daily weather briefings via telephone, press releases, 2 CBC radio interviews. Training Documentation on Climate and Weather was prepared for the Canadian Farm Business Management Training Project (Regional Development and International Affairs Branch).

Climatic data from nine stations in northern Ontario, Ontario Department of Northern Development; two articles for Agriculture Canada and a report for the Canadian Climate Program on the Agriculture Sector were prepared. A report was prepared for the Task Force on Agricultural Weather Service for Canada and presented to CASCC.

The Agrometeorology Data Bank was maintained and new data were edited; total holding is now 320 stations. Provision for direct computer access by Branch establishment to both current and historical data has been initiated.

(d) Swift Current Research Station

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

Because of the long-term nature of this objective the research projects under this program have changed very little since 1979. For a more complete description the reader is referred to Canadian Geophysical Bulletin, Vo. 32, pages 111-113.

19. Canadian Forestry Service

(a) Newfoundland Forest Research Centre

Climate data are being used in the development of ecoregions for Newfoundland. This includes producing climatic diagrams for different regions, observing phenological development of plants in different habits, and freeze-thaw cycles in mineral and organic soils. In connection with genetic improvement studies site meteorological factors are being correlated with growth and yield, to help delineate growth and seed zones. Several studies are in progress: to correlate tree ring width with extreme dry years, past climate and fire history in central Newfoundland; and to discover the influence of weather on population fluctuations of softwood defoliators, to define "developmental" zones and relate these to climatic zones on the island.

(b) Maritimes Forest Research Centre

A cooperative study of the dispersion of spruce budworm moths by the MFRC, the Atmospheric Environment Service and the University of New Brunswick has been ongoing since 1973. This has involved the use of radar, instrumented aircraft and observations from platforms extending above the forest canopy. A final report on wind patterns in the Maritimes and their relation to dispersal and distribution of spruce budworm moths was completed. This establishes the importance of wind direction, marine and land wind flows and canopy temperature in determining when moths can fly and where they are dispersed. A Sangamo Type A automated monthly precipitation collector is now operated at Acadia FES to serve as part of CANSAP, and to provide information for local LRTAP studies. In this connection a laboratory rainfall simulation apparatus is to be developed for screening the relative sensitivity of native tree species to acid precipitation. Analysis of New Brunswick meteorological data was completed as input for devising an ecological forest site classification and mapping system for the province. A publication on the climatological regions of New Brunswick is to be prepared.

(c) Laurentian Forest Research Centre

A recent study was established as part of the LRTAP program at Lac Laflamme in the Montmorency Experimental Forest to determine long-term effects of air pollutants, including acid precipitation on the watershed. Climatic studies of the watershed are also being undertaken.

Several reports have been prepared on the effects of acid precipitation in the forest and aquatic ecosystem.

(d) Petawawa National Forestry Institute

Studies being conducted at PNFI are as follows:

(i) Forest Wind

Major emphasis continues on modelling and measuring wind over rough forested terrain. One automatic weather station reporting via GOES has been established on open terrain. Eight 32-m masts have been erected in the forest, one at a standard site and seven across a topographic feature. The masts will be instrumented, starting in April, 1981.

(ii) Drought

Twenty-seven years' data from 45 stations across Canada are being analysed to discover the relationship of weather to severe fire seasons.

(iii) Frost Damage

Temperature profiles at two 20-m masts will be used to determine the dependence of frost damage incurred by red pine flowers on the severity of frost.

(e) Great Lakes Forest Research Centre

Synoptic hourly station data are currently used to calculate the fire weather index for wildfire case studies and for the provincial fire station network north of 52°N. They are also used for relating weather conditions at critical times of the season to germination, survival and growth in regeneration silviculture, for assessing conditions for insect control operations, such as aerial spraying and distribution and persistence of sprays, and for directly studying important forest damage losses resulting from such environmental occurrences as windthrow and drought stress. Climate station data are used for: calculating moisture deficiencies in wildfire case studies and post-fire regeneration studies; estimating drought code values; performing dendroclimatological analyses; computing fire-climate statistics for park fire management planning; modelling environmental conditions during initiation of insect outbreaks; and comparing successes or failures of regeneration trials.

(f) Northern Forest Research Centre

A new study was initiated in 1979 to use the period of climatological instrumented records and proxy data from the boreal forest zone to establish the history of climatic variations and relate this to forest biomass productivity. Two contracts, parts of the ENFOR program, are currently under way to assist this study; (a) a literature review of the impact of climatic variation on biomass accumulation in the boreal forest zone; and (b) a pilot study of tree-ring chronologies and the impact of climatic variation on boreal forest biomass productivity. The latter study involves collecting tree-ring data from five or more sampling sites along two north-south transects through the boreal zone, using 200+ year old white spruce as the sample species. In 1979/80 samples were collected along an Alberta/Northwest Territories N-S transect from west of Sundre to east of Yellowknife. The second set of samples will be taken in 1981 along a transect near the Saskatchewan/Manitoba boundary.

A study was completed on the interrelationship of trends of defoliator insect populations and weather and other environmental factors in Manitoba and Saskatchewan. Climatic data are being provided: for a cooperative study with the Alberta Forest Service to develop a biogeoclimatic ecosystem classification for Alberta; and for a new watershed model using an existing model (PROSPER) and a new snowmelt model to simulate generated runoff. Analysis continues on the effect of the microclimate of clear-cut areas on pine and spruce seedling growth. Climate data are used in studies of forest hydrology dealing with fire behaviour and management, and air pollution injury to vegetation. The latter included collecting and analysing precipitation samples for pollutant and nutrient elements. Two climate stations were equipped during the last three summers to monitor field performance conditions, especially frost tolerance, of containerized conifer seedlings south of Grande Prairie. A contract study was completed to establish the nature of the environment for overwintering containerized stock at nurseries in the Prairie Provinces and to recommend modification of practices, and requirements for monitoring climate parameters. Climate-vegetation relationships continue to be studied to describe the ecoregions of Canada, and the paleoclimate of the Holocene as it relates to the distribution of trees and other plant species, especially near their limits of occurrence.

(g) Pacific Forest Research Centre

Work continues on adapting numerical wind models to forestry problems such as budworm dispersal and smoke management. Field experiments have concentrated on obtaining some of the data base required for the modelling studies. Investigations continue in applying climate series and topographic variations in climate to problems relating to pest populations and forest fires. Development of meteorological instrumentation for forestry needs continues; a note on a crystal-controlled theodolite timer was published. A new 5-year cooperative discipline study, mainly funded by the B.C. Ministry of Forests, has been initiated to follow the fate of fertilizers applied on snow; the first test area is near Spillmacheen.

20. Atmospheric Environment Service

(a) Meteorological Services Research Branch (MSRB)

(i) General Program

The general program of the Meteorological Services Research Branch was outlined in the 1979 Canadian Geophysical Bulletin.

(ii) Detailed Studies

Many changes were made in the parameterization of physical effects in the spectral model, including the addition of a field representing the sub-surface soil temperature. Routine snow cover analysis replaced climatology; improved calculations of albedo and soil moisture were introduced.

The limited-area finite-difference primitive equations model was brought to peak performance, but proved to be no better than the quite similar American LFM and was therefore retired.

The efficiency of the variable resolution three-dimensional finite-element model was improved to the point where it was accepted for operational use, to be integrated on request in situations requiring finer resolution than that of the spectral model. Changes were made in moisture, convection and surface friction computations

resulting in greatly improved precipitation forecasts, the primary goal of the model.

Many experiments on normal mode initialization were successfully carried out with the new version of the spectral model. The addition of the 50-mb level to the operational objective analysis system proved to be beneficial.

A new semi-Lagrangian method of integration which permits much longer time steps was investigated. Experiments with a non-divergent barotropic model gave virtually identical results for Lagrangian or Eulerian integrations. Some differences appeared in the divergent barotropic case, but the causes have since been diagnosed.

Work continued on the Beaufort Sea Winter Ice Experiment, which was described in the 1979 Canadian Geophysical Bulletin. A meteorological, oceanographic and ice information data base was assembled and used in developing fine-mesh and regional scale ice prediction models suitable for application in winter ice conditions. A second comprehensive data acquisition phase was planned to provide an independent data set for testing the models. A more advanced version of an ice prediction model applicable to unconsolidated pack ice was developed and selected historical cases were tested. A thermodynamics model capable of predicting ice freeze-up, growth and ablation was also developed and given initial testing. These ice prediction models are for selective use in support of marine operations in any Canadian geographical location and in any season.

Development of procedures for the diagnosis and empirical-physical prediction of weather parameters reached the implementation stage in several instances. A statistical procedure applied to physically significant meteorological and geophysical parameters for predicting probability of precipitation has been installed at the Canadian Meteorological Centre and is operational for 72 locations across Canada. A model to predict snow squalls induced by water bodies was installed at Ontario Weather Centre and operational testing commenced. The value of meteorological analyses in isentropic coordinates was demonstrated in operational tests and is being documented and packaged for implementation in Regional Weather Centres. So far, its most useful applications appear to be for severe local storms and forecasting of heavy precipitation. A polynomial interpolation procedure for analysing selected meteorological parameters was documented, for further implementation.

Work still being evaluated includes a pattern correction procedure for short-range prediction (up to about 12 hours into the forecast period) of selected meteorological fields, a K-profile version of a planetary boundary-layer prediction model, and an analytical shape-fitting procedure for classifying and verifying meteorological fields.

Research studies were carried out on (a) potential applications of SEASAT data, especially its use in ocean wave forecasting, (b) prediction of surface winds with a mesoscale model, including participation, in a project of the International Energy agency and (c) a Markov chain procedure for short-range aviation weather forecasting.

A manual adaptation of the AES oil spill trajectory model was developed and documentation was distributed to several Weather Centres. The procedure was used to respond quickly and provide slick movement forecasts for several potential and simulated oil spill emergencies during the year. Plans were prepared for development of an AES fast-response system that could be operated on computer facilities in MSRB and the Regional Weather Centres.

The Aerospace Meteorology Division is continuing development of a system to integrate weather radar and meteorological satellite data and produce short-range precipitation forecasts.

A system to extract aerological temperature and humidity information from the TOVS sensors flown on the NOAA satellites has been designed to provide meso- and regional-scale data for use in severe weather forecasting. The prototype system is being developed by the Division in conjunction with MacDonald Dettwiler and Associates as part of the Federal Government Cooperative Programs with Industry (COPI) program. First tests are expected in the spring of 1981.

The Ice Status Monitoring System is a computer-assisted image analysis system that is being developed in cooperation with the Ministry of Transport for use in sea ice forecasting. The first task completed was a precision remapping capability to allow temporal as well as multi-spectral analysis of satellite radiances, and was carried out by MacDonald Dettwiler and Associates in Vancouver.

The Division is involved in research and development in the area of microwave sensing. Most of the past effort was aimed at participating in the Canadian SURSAT program and in NASA science and validation programs associated with SEASAT. Recently the emphasis has been shifted toward developing the AES capability to utilize data resulting from the United States NOSS program.

Activities in the Satellite Data Laboratory and in wind engineering research are as reported in the 1979 Canadian Geophysical Bulletin.

(b) Atmospheric Processes Research Branch

(i) Experimental Studies Division

The radiation monitoring program was enhanced by adding measurements of UVB with the Smithsonian instrument. Continuous measurements of the long-wave fluxes are being made with pyrgeometers. Instrument development included: placing the AES Mark II sunphotometer into commercial production with Sonotek Ltd.; and testing the AES automatic suntracker prototype and constructing three production prototypes. More Phase Two multipyranometer data have been recorded to extend their solar energy statistics. AES scientists participated in the Fifth WMO International Pyrheliometer Comparisons.

The New Mark II ozone spectrophotometer was tested and is ready for commercial production. The interference of sulphur dioxide with Dobson total ozone measurements was further evaluated. Sulphur dioxide is monitored routinely at Toronto with the Brewer spectrophotometer, yielding total column amounts of 4 to 5 m atm-cm. Daily surface-based measurements are continuing at Churchill, Edmonton, Goose, Resolute and Toronto. Vertical ozone profiles up to 30 km are determined at the first four locations every Wednesday by balloon soundings using electrochemical sondes.

Theoretical simulations of constituent data sets from STRATAPROBE flights indicate that hydroxyl densities in the 15 to 30 km region are low. The consequences of these low densities on the depletion of ozone by fluorocarbons were evaluated by means of a scenario model. Predicted depletion of ozone at current usage rates is less than 10%; the expected 1980 depletion is less than 1%. An experiment in collaboration with NASA Goddard scientists was conducted at the National Scientific Balloon Facility in Texas during October to test the theory that yielded the low values of hydroxyl density.

(ii) Cloud Physics Research Division

The Division concentrated on the experimental and microphysical aspects of cloud and precipitation physics, particularly related to weather modification and the prospects of rainfall enhancement; and on radar meteorological studies directed toward the measurement of precipitation, and the examination of the mesoscale structure of storms and the life cycles of precipitation cells.

The Division again participated for a 4-week period in June in the U.S. Department of the Interior High Plains Cooperative Experiment (HIPLEX) at Miles City, Mont. The National Research Council Twin Otter aircraft, which is particularly well-instrumented for cloud physics studies was flown for the second year to collect a significant amount of data on microphysical and dynamical parameters from cumulus clouds that are similar to the Canadian clouds previously studied. Analysis and research of the data continues.

The Division organized and hosted an experiment to intercompare airborne devices for measuring cloud liquid water contents, making use of a particularly appropriate NRC wind tunnel. Participants from other countries and other cloud physics groups contributed to the success of this unique experiment allowing data comparisons to be placed on a much firmer foundation.

The radar group participated in the World Meteorological Organization (WMO) Precipitation Enhancement Project (PEP) in Spain, by providing a radar digitizer-recorder system, interfacing it with a U.S.S.R. weather radar and operating it during the February to May field season. Data are being analysed by McGill University and the University of Toronto to determine whether the Spanish locale is climatologically suitable for a long-term project to evaluate experimentally and statistically various weather modification hypotheses.

The Division also participated in the field program of the northeastern Pacific Storm Transfer and Response Experiment (STREX) in November and December. A radar digitizer-recorder was adapted to the radar on one of the prime ships, the CCGS Vancouver, and produced data that will be used to document the mesoscale life cycles of north Pacific storms and increase the understanding of precipitation formation mechanisms. Data analysis is beginning.

A newly conceived real-time weather radar display with remote transmission capabilities was developed and installed in the Ontario Weather Centre. It has also found practical use by hydrologists, conservation authorities, power companies, transportation services, and local TV media. Studies are nearing completion on the reliability of radar in providing quantitative areal precipitation estimates. Suitable correction factors have been developed. A radar echo climatology is being amassed to determine, among other things, local effects on precipitation development and preferences. The measurement of snow is receiving special attention.

(c) Air Quality and Inter-Environment Research Branch

(i) Long-Range Transport of Air Pollutants (LRTAP)

The primary AES contributions to the LRTAP scientific program are concentrated in the areas of:

a) Atmospheric transport, transformation, deposition, and modelling.

b) Calibrated watersheds. (See the 1979 Canadian Geophysical Bulletin for further details concerning these two areas).

c) In addition to these research activities, scientific program coordination and LRTAP liaison offices were established. These are responsible for coordinating the various elements of the LRTAP Program of all departments and providing advice and current information on the liaison and financial aspects of the program to senior management, elected officials, the media and general and specific public groups.

(ii) Environmental Monitoring

The Canadian Network for Sampling Precipitation (CANSAP) operated throughout the year with 54 stations. The collectors that were not upgraded during 1979 were attended to in 1980 to bring the entire network up to the same standard in precipitation collectors.

The joint sampling program with the Ontario Ministry of the Environment was concluded. Data are being evaluated by the Ministry. Intercomparison of precipitation data of CANSAP with those of the National Atmospheric Deposition Program (WADP) is to begin in April 1981: CANSAP stations will be located at Glacier National Park (Montana), Michigan State University Biological Station (Michigan) and Caribou (Maine); WADP stations will be located at Lethbridge (Alberta) Mount Forest (Ontario) and Kejimikajik (Nova Scotia).

The Inland Waters Directorate (which provides the laboratory for analysing CANSAP samples) took part in the Fifth Intercomparison of Methods, sponsored by the Norwegian Institute for Air Research. A report on the fourth intercomparison indicated that the Canadian laboratory compared very well with other European laboratories. A report has been received from Pennsylvania State University on the intercomparison of precipitation samplers.

Assessment of the CANSAP network has begun -- the first phase being an evaluation of specific sites -- a full evaluation of the network will be made during 1981.

Two new sunphotometers have been purchased and tested. As a result, six more instruments have been ordered to equip the WMO network.

As part of the WMO background monitoring program, flask sampling was continued at three Canadian sites to obtain atmospheric CO₂ data. Additional samples were obtained at Cape St. James, B.C. to determine site suitability as a replacement for Ocean Weather Station "Papa".

(iii) Great Lakes Water Quality Agreement (GLWQA) Program

The Branch is supporting the GLWQA program through two separate research programs, as outlined in the 1979 Canadian Geophysical Bulletin. In particular, equipment for generating tagged, monodisperse aerosols has been constructed and tested for application in field studies of uptake by artificial collectors.

(iv) Criteria and Standards

The Branch provides scientific and technical support to the Federal/Provincial Committee on Air Pollution through its Subcommittees on Air Quality Objectives and Air Quality Indices. For the Objectives Subcommittee, a criteria digest describing the effect of combinations of common air pollutants on various receptors is in the final stages of preparation. The review of the existing ambient air quality objectives for ozone has begun with the preparation of a criteria digest for this gas. Based on a nitrogen dioxide review document prepared by AES, a decision has been made by the Sub-committees to leave the existing ambient air quality objectives unchanged.

Research into cause-effect relationships between various common air pollutants and various receptors has concentrated on injury to higher plants and lichens by pollutants acting singly or in combination in both the field and laboratory situations.

A Panel on Particulate Matter Effects on Atmospheric Processes is preparing input to the Air Subcommittee of the NRC Associate Committee on Scientific Criteria for Environmental Quality.

(v) Environmental Impact Assessment (EIA)

In direct support of the Departmental EIA program and other agencies, the Branch reviewed about thirty-five (35) EIA documents. A significant number of these reviews dealt with oil explorations and pipelines (particularly in the Arctic), while others dealt with impacts from radionuclide releases (such as from uranium mining developments). A review of the Norman Wells Pipeline EIA led to formal participation at the EARP public hearings held in Yellowknife.

In support of EPS a modelling assessment was carried out to estimate impacts of continuous radionuclide releases from the Pickering Nuclear and the Lakeview Thermal Power Plants. Support was provided to AES Central Region in their assessment of impacts on air quality near MacGregor, Manitoba arising from an accidental tank car spill of vinyl chloride, a dangerous heavy gas.

Impact assessment research continued on air pollution potential in Canada and on development of numerical models for assessing air quality impacts for various environmental conditions. Under the formal activity, a short duration intensive rawinsonde study was conducted at Resolute Bay, N.W.T., with cooperation of AES Western and Northern Regions, to determine the stability characteristics of the atmospheric boundary layer during polar night (mid-winter) and daylight (mid-summer) conditions. Also, projects to develop two new air pollution potential data sets were initiated:

- (i) A stability analysis of the lowest 3 km of the atmosphere, and,
- (ii) An analysis of maximum afternoon and minimum morning mixing depths. Both data sets contain eight (8) years of radiosonde data from North American stations including Alaska and from Greenland. They will be used in climatological air pollution models and incorporated into the Atmospheric Interactive Modelling System (AIMS).

In addition, analysis of wind profile data from an earlier 4-year mixing depth study has generated velocity ratio and power law statistics for all of North America. These seasonal and regional

values are more accurate than a single constant value for use in Gaussian Dispersion Modelling.

Modelling activities included the following:

- a) A gaussian puff model was devised for short-range transport and diffusion of radionuclides. The model is updated with the physics of limited mixing and is being tested with different sets of diffusion coefficients.
- b) A Gaussian dispersion model was developed to calculate exposure (time integral of air concentration) and ground concentration that is due to deposition from instantaneous, finite, and continuous pollutant releases. It was applied to an International OECD Benchmark Problem describing an accidental radionuclide release at a nuclear plant. Processes of radioactive decay, and dry and wet deposition were treated in the scheme. Results compared reasonably well with those of more sophisticated schemes.
- c) A long-range climatological diffusion model, described by a simple analytical equation, is being investigated for use in the long-range transport program. It has been tested for a single source and is now being adapted to simulate pollutant concentration over North America using a source inventory for the continent.
- d) A hydrological model of the water budget of a snowpack was modified to incorporate pollutant accumulation resulting from deposition. Work is under way to apply the technique in eastern Canada to assess acidic snowmelt shock potential.

Technology transfer activities:

- a) The one-week course on Air Pollution Meteorology was presented in Vancouver, B.C. and Bedford, N.S. to federal, provincial and industrial representatives.
- b) A new initiative was undertaken to establish a national Atmospheric Interactive Modelling System (AIMS) in cooperation with Dataline Systems Limited (a computer service firm).

The purpose is to place atmospheric models on a central interactive computer system accessible to users across Canada. Implementation of several models is progressing.

- c) Work continued on preparation of user guides for the various models that have been developed. This activity is geared to support the AIMS program directly.

(vi) Canadian Arctic Air Pollution Program (CAAPP)

The CAAPP is the Canadian component of a joint study with the governments of Norway, Denmark and the United States to investigate suspended particulate matter north of 60°N. Objectives of the program are given in the 1979 Canadian Geophysical Bulletin.

In support of CAAPP activities air parcel trajectories were computed, using a recently developed trajectory model, for two reasons, spring 1979 and winter 1979/80. The results indicate that

the arctic atmosphere was more stagnant (self-contained) with lighter winds in spring than in the following winter. Hence, air pollutants from industrial activity in Siberia, Europe and eastern North America are injected into the arctic atmosphere predominantly during winter months. Further work is under way toward compiling a seasonal climatology of air parcel trajectories into the arctic.

(vii) Nanticoke Environmental Study

The Nanticoke Environmental Study was a major field program carried out in June 1978 in cooperation with AES Ontario Region, Ontario Hydro and the Ontario Ministry of the Environment to investigate shoreline effects on the diffusion of pollutants from the coastal thermal power generating station.

(viii) Environmental Contaminants

The Branch contributes to the Federal Environmental Contaminants Program established under The Environmental Contaminants Act (1976) by undertaking research on the behaviour of atmospheric inorganic (metal) and organic contaminants interacting with the biosphere. Specific objectives and contaminants are presented in the 1979 Canadian Geophysical Bulletin.

A fluorescence mercury monitor is being developed and is almost ready for laboratory testing. It should have greatly enhanced sensitivity as well as the ability to determine directly the different species of mercury present in the atmosphere. Measurements of mercury vapour using trapping techniques were also made from an instrumented aircraft during the PEPE (Persistent Elevated Pollution Episodes) study.

Organic compounds in the atmosphere are also receiving increased attention. The newly acquired gas chromatograph-mass spectrometer (GC-MS) was being prepared for operation at AES, Downsview. This instrument will permit recognition and unambiguous identification of the full range of organic contaminants residing in the atmosphere. Two sampling sites are being readied to obtain vapour phase organic samples for the GC-MS.

(ix) Modelling and Numerical Studies

a) Dispersion Modelling

A Monte Carlo simulation model of transport and dispersion of pollutants in the surface boundary layer has been used to assist in the optimal determination of parameters in operational dispersion models. Development of the Lagrangian simulation model, to allow for a partially reflecting lower boundary, has also been initiated.

b) Boundary-Layer Flow in Complex Terrain

A model of boundary-layer flow over isolated low hills has been developed and tested. Modification of the model to improve its performance when applied to real terrain are in hand and comparisons with field and wind-tunnel data are planned for early 1981. This model is well suited for evaluating sites for wind power installations, and for estimating wind loads on structures in complex terrain.

c) Three-Dimensional Mesoscale Model of the Planetary Boundary Layer

A final report containing the detailed formulation of the three-dimensional hydrostatic model of the planetary boundary layer (PBL) was written. Results are presented for a numerical experiment in which surface roughness length varies over a domain of size 85 km x 65 km. Except for the presence of variable roughness and the absence of a slightly stable thermal stratification, the model simulates conditions of the well-known Leipzig Wind Profile.

d) Shoreline Fumigation

A model has been developed combining the elements of plume rise in stable stratification, internal boundary-layer entrainment growth, mass entrainment across an interface, and subsequent fumigation that are appropriate to the situation that existed at Nanticoke, Ontario during a 1978 field experiment.

e) Gas Transfer at the Air-Sea Interface in Breaking Waves

One problem vexing the area of gas transfer between the atmosphere and oceans or lakes is the lack of a model for the apparent increased sensitivity to wind above a threshold identified with the initiation of breaking waves. A model has been prepared that combines concepts of drag associated with breaking waves with rough wall mass transfer prorated for localized transfer in patches of whitecaps.

f) Polynya Modelling

A report on the numerical study of flow over a polynya to estimate the flux parameters over the fetch of an arctic open land has been completed.

(x) Field experiments and data analysis

a) Storm Transfer Response Experiment (STREX)

The Boundary-Layer Research Division of AES has been participating in a joint Canadian/American experiment called STREX (Storm Transfer and Response Experiment), whose general objective is to understand the physical processes of the boundary layers of atmosphere and ocean in mid-latitude storms. The experiment was conducted in the vicinity of Ocean Station P (50°N, 145°W) from November 2 to December 15, 1980. Intensive meteorological and oceanographic measurements were taken from the CCGS Vancouver, and a complementary set of data from the NOAA ship Oceanographer, located east of Station P. Within this background framework, specific frontal events were identified for investigation by aircraft that flew missions in the vicinity of Station P to measure turbulent fluxes in the lower boundary layer and determine the scale at which transfer occurs at various heights. Arrays of drifting buoys and satellite coverage enhanced the scope of data obtained.

b) Polynya Heat Budget Experiment

The third year of the three-year Polynya Study was undertaken in cooperation with the Frozen Sea Research Group

of Ocean and Aquatic Sciences (Department of Fisheries and Oceans). Wind and temperature profile data were obtained in the lee of open water with fetches ranging from 250 m to 1 km.

c) Boundary-Layer Structure

Analysis of the 1978 Nanticoke Field Study has revealed the existence of classical internal boundary-layer structure. The growth of the depth of the boundary-layer inland from the shore of Lake Erie, when the water is considerably colder than the surrounding land, has been shown to obey well-known relationships for entraining interfaces.

d) Microwave Scattering Characteristics and Emissivity of Wind Waves

Interpretation of the satellite interrogation of the sea surface waves. A model has been developed to characterize the spectrum of gravity-capillary waves in terms of the wind stress and the minimum phase velocity associated with the threshold for wave breaking. The development requires consideration of the reduction in scattering (increase in emissivity) resulting from foam and whitecaps. Comparison with various aircraft-based scattering and emissivity studies is satisfactory. Future work will concentrate on analysis of specific satellite (SEASAT) data. A multiple-agency program to analyze parts of the parameterization problem, in support of a future satellite system (NOSS), is contemplated.

e) Port Hope Field Study

The Port Hope Field Study has three basic objectives: 1) to obtain information on the rise and dispersal of the Eldorado Nuclear pollutants as a function of different wind conditions; 2) to investigate the building's effects on the dispersion of the pollutants; and 3) to provide wind data to support other facets of the total air quality program. The study has produced comprehensive and valuable information on the downdraft from a Nuclear Plant.

(d) Canadian Climate Centre

(i) Introduction

The Canadian Climate Centre (CCC) provides a central focus for climate activities in Canada relative to research, data management, information services, applications, impacts, monitoring and prediction.

Canadian Climate Program (CCP) - The year 1980 was busy and formative for the Canadian Climate Program. A series of Workshops and meetings was convened across the country.

Evaluation of the needs for service that were expressed in the Workshops and discussion groups and in surveys sent to thousands of other users formed the basis for two draft documents on the CCP tabled at the November meeting of the Climate Planning Board, "Canadian Climate Program - A Plan for Action" and "Canadian Climate Program - Needs and Recommendations."

The Canadian Climate Program office was actively planning for a national seminar sponsored by the Canadian Council of Resource and Environment Ministers (CCREM), to be held March 17-19, 1981 at Regina on the effects of climate on various Canadian socio-economic sectors.

(ii) Data Management Division

A number of activities were commenced in 1980 to introduce automated methods into the data management system. One method involves collecting and processing solar radiation data using a tape cassette acquisition and decode system with quality control exercised by means of graphical editing on a CRT. Quality controlled data will be entered directly into the archive files. The Aerological Data Reduction System (ADRES) was implemented for upper-air data. Winds are recorded each minute and all data are stored on diskettes for mini-computer processing.

With the acquisition of the AS/6 computer system at AES Downsview, development of an on-line data collection system was started. Teletype traffic for hourly weather, and synoptic reports from land stations and ships will be collected on disc files. Plans call for automated quality check programs to discover erroneous data which will then be edited for quality and directly input into the archive via remote CRT terminals.

Plans are well under way to develop systems to randomly access climatological data files and relevant information about all observing stations.

(iii) Climatological Services Division

Demand for climatological services continued to grow. Climatological data were supplied in response to more than 17,000 requests; specialized services were provided in more than 320 instances that required archive copy or computer-produced statistical analyses.

Approximately 6,500 pages of historical data were published in regular periodicals, and another 1,500 pages of reports and summary material were published dealing with Canadian Program workshops and meetings. Nearly 800,000 climate documents were microfilmed during the year.

Almost the entire archive has been converted to a simplified metric format. Commencing 1980, the archive will be updated annually.

A program reporting the major impacts of climate was undertaken. A selection of clippings from Canadian daily newspapers and trade and news magazines was collected and filed. Briefings at which CCC specialists report on climatic impacts and their consequences for society, the economy, and the Canadian environment were held.

(iv) Hydrometeorology Division

A three-year project to implement a flood forecast and warning system in Colombia was successfully concluded on behalf of the Canadian International Development Agency.

Weekly water budgets continued to be processed and mapped in near real-time for all of Canada. In collaboration with Inland

Waters Directorate, a drought study was initiated for the Canadian prairies.

Intensity-duration-frequency curves are now available for 450 stations across Canada, including automatic recording gauges in remote regions. Regional maps of these rainfall statistics are being prepared. Statistical studies examined: the frequency of extreme rain occurring simultaneously with frozen ground and snow-melt; the time distribution of precipitation during one- and twelve-hour storms. Quantitative radar data from five SCEPTRE radars continue to be received and analyses on request for areal precipitation accumulation. Satellite-derived maps of snow cover in the Saint John Basin were provided operationally to the provincial flood forecasters during the 1980 melt period.

With the increasing importance of offshore production and transportation of hydrocarbons, emphasis continued on analysing relevant climatological data for marine areas. Airborne radiometer surveys of Great Lakes temperatures are being replaced by analyses for the Great Lakes and East Coast marine areas using digital infrared data from the TIROS-N and NOAA satellites.

Spatial analyses of meteorological parameters at grid points were extended to include the water equivalent of snow on the ground, temperature, precipitation and surface water temperature in New Brunswick and British Columbia. The Lake Okanagan evaporation study involved two major field investigations and the monitoring of meteorological conditions around the lake. Continuing snowfall-snowpack investigations include: measurement of snowfall in low precipitation regions (Prairie, Arctic); water equivalent of fresh snowfall at climate stations; development of the Nipher-type shield for recording gauges; metrication and standardization of snow samplers.

(v) Applications and Impacts Division

Offshore climate conditions continued to have a high priority because of their importance in design and operations, oil and gas exploration and shipping, and environmental impact assessment. Lancaster Sound was given special attention with the development of a synthetic wind and wave climatology. Regional studies of the Canadian Arctic Islands and an evaluation of wind and temperatures for determining shipping zones in Arctic waterways were completed.

Prairie drought was the major weather event in Canada during 1980. To learn more about the frequency and impact of such events on the economy and society, a continuous water budget model was implemented to identify prolonged soil moisture deficits on a grid-point basis.

Popular accounts of the climate of Ottawa-Hull and effects of climatic change on cottaging and other recreational activities in Ontario were completed in manuscript form. Other local climate studies dealing with the Mackenzie Delta and the Eardley Escarpment in Quebec were also completed.

Analysis of 1979 data in connection with the Spruce Budworm Moth dispersal in New Brunswick was undertaken. A mobile survey of ozone concentration in southwestern Ontario was conducted to find alternative areas suitable for growing white beans where the exposure to high concentrations would be minimal. A report on environmental impacts on forests and climate was prepared relative

to energy production from forest biomass. Other biometeorological activities included study of the impact of climate on the Niagara fruit belt and further analysis of soil characteristics of selected Canadian sites.

In energy applications, work on the solar radiation and meteorological merged data base proceeded with development of techniques to fill in gaps in the radiation file. Other studies included: use of satellite data to determine solar radiation at the earth's surface; evaluation of models for estimating incoming solar irradiance; and testing and development of wind profile models for the first 250 m of the atmosphere.

In industrial applications, work proceeded on development of a population weighted heating degree-day index for Canada, calculation of design temperatures for a number of Canadian locations, development of national tornado statistics, and initiation of study on the long-term climatic effects of the eruption of Mount St. Helens.

(vi) Numerical Modelling Division

The AES multi-level spectral atmospheric general circulation model (GCM) was considerably modified during 1980. The model is now routinely integrated using ten levels in the vertical and horizontal triangular truncation at 20 waves. The boundary-layer parameterization scheme has been reformulated and the radiation calculations have been greatly modified. A long simulation over the annual cycle is in progress. Special runs using three levels in the vertical are also being made as part of a study leading to development of an interactive mixed layer ocean model to provide lower boundary information for the GCM. Work also continues on interactive cloud parameterization using the GCM.

The two-level spectral GCM employing Mintz-Arakawa physics gives poor simulations in the lee of high mountains. This problem is under study using the three-level version of the multi-level GCM to determine whether this result is generic to low vertical resolution spectral GCM's or peculiar to the two-level model.

Numerical experiments continued with the stratospheric two-dimensional model to determine more realistically the possible impact of fluorocarbons and increased atmospheric N₂O on stratospheric ozone and temperature. The effect of stratospheric ozone reductions on the amount of solar UV-B radiation (2900-3200 Å) reaching the earth's surface is also being investigated.

The general circulation diagnostic package was expanded. A new formalism for deriving diagnostic equations in pressure coordinates that properly takes account of the presence of topography has been developed and applied. The diagnostic programs are used to assess the ongoing GCM simulations. Analysis of three months of level III-a FGGE data is nearly completed and study of the level III-b data has begun. Several months of data from objective analyses of the Canadian Meteorological Centre have been diagnosed and archived. Other diagnostic studies performed include the analysis of January and July global FGGE III-a data in terms of spectra and fluxes of kinetic energy, enstrophy and available potential energy for the two-dimensional spherical wave number n .

(vii) Monitoring and Prediction Division

Current development projects involve the design and implementation of a computerized system for interactive analysis of near real-time data. The system will allow comprehensive analyses of data for the weekly publication Climatic Perspectives. Data capture systems are being developed for the new AS/6 computer to take full advantage of the future on-line climatological archives and the local graphics facilities.

Research is continuing in the modelling of time series with autoregressive integrated moving average models. An extensive set of independent 500-1000 mb monthly thickness forecasts for the Northern Hemisphere has been generated and verification studies are under way. A multivariate correlation model will be used to relate thickness anomalies to surface temperature anomalies.

Diagnostic studies of monthly and seasonal anomalies of temperature and heat fluxes in the lower troposphere have been started. Plans include investigation of circulation statistics in both geographic and Fourier spaces and study of unusual situations.

(e) Central Services Directorate - Ice Branch

Operational support of marine activities in ice-covered waters continued throughout the year, concentrating on southern and eastern waters during the winter season and on the Arctic during summer. A light ice season in the Gulf of St. Lawrence resulted in a slightly lower total level of airborne data collection, with about 2500 hours of chartered reconnaissance time. Of these, about 1350 hours were flown with the SLAR-equipped aircraft. Satellite data continued to provide an important supplementary information source, with coverage from TIROS and LANDSAT systems being available in near real-time over all marine areas except in the Eastern Arctic. A cooperative Canadian - Danish effort to establish a TIROS receiving station at Sondre Stromfjord, Greenland, to fill this gap is now nearing completion and is expected to be operational by June 1981.

All data collected, both airborne and satellite, are archived by the Ice Climatology and Applications Division in Ottawa and are available to the general public. Publication of data in ice chart format is proceeding at a slightly accelerated rate, with current emphasis on updating the Summary and Analysis series for the Eastern Seaboard. Publication of ice atlases for the Arctic and the Eastern Seaboard, providing means and extremes of various digitized ice parameters over an 11-16 year period, is expected to be completed in January 1981.

Remote-sensing activities, in addition to operational data collection, concentrated on analysis of existing data sets and participation in SURSAT and radar satellite projects. The AES participated in the 1979 Winter Ice Experiment Beaufort Sea (WIEBS) experiment through SLAR data analysis modelling and project management. Summer students were employed to undertake ice dynamics studies using SLAR imagery and analysis of laser profilometer traces for topographic information. Several applications of SLAR imagery for measuring various ice parameters, including icebergs, are also being studied. SURSAT activities included participation in an ice workshop held at AES Headquarters in June, and completion of several SURSAT study reports. Active involvement in the radar satellite project commenced in the fall of 1980, with Dr. Ramseier, Ice Branch senior research scientist, taking a lead role in studying ice-user requirements.

(f) Field Services Directorate

As part of its responsibility for operating the Canadian weather forecasting system, the Field Services Directorate manages an extensive network of stations to collect weather data.

Field Services Directorate is actively involved in developing, field testing and installing various automatic meteorological sensing devices as part of AES marine, land and upper-air automation programs. The Automatic Data Reduction System (ADRES) will automate most of the computational work involved in manipulating upper-air data. The Remote Environmental Data Acquisition Concept (REDAC) is the next generation of modular automatic surface instrumentation. The marine program is proceeding on two fronts led by the need to provide replacement systems for the two Pacific weather ships that will be decommissioned in July of 1981. The ocean buoy replacement system under development will provide a device suitable not only for drifting or ice buoys but for on-ships installation as well. Finally, the meteorological communications network is being redefined so that the resulting reconfiguration will likely involve greater use of communications satellites and regional computers for data collection and distribution.

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VII OCEANOGRAPHY

Compiled by G.T. Needles

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2. Dalhousie University
3. Bedford Institute of Oceanography
4. Université du Québec à Rimouski
5. Peches et Oceans, Région du Québec
6. GIROQ
7. McGill University
8. Ocean and Aquatic Sciences, Central Region
9. National Water Research Institute
10. Fisheries and Oceans, Ottawa
11. University of British Columbia
12. Royal Roads Military College
13. Institute of Ocean Sciences, Sidney, B.C.
14. Bibliography

1. Memorial University

(a) Centre for Cold Ocean Resources Engineering

Nineteen eighty has seen some significant changes in C-CORE's activities as several major projects reached their final stages. The Impulse Radar System for sea ice sounding is now operational and has received MOT approval. Our study of the Kurdistan spill of oil in ice was concluded, and studies of the fine scale modelling of sea ice movement and of the bearing capacity of ice covers were completed. The effectiveness of positional radar for monitoring ice movement was successfully demonstrated and a theoretical study of ice forces against structures is in press.

C-CORE's investigation of iceberg scouring continues. During 1980 field studies were concentrated on the Grand Banks. Additional voyages to the region will be made during 1981.

The Centre's oil in ice program currently involves investigating dispersion processes and methods for detecting oil in ice; participation in experimental spill projects is ongoing. Oilspill counter-measures systems development is being undertaken for oil in ice, as well as for heavy oil in open ocean areas. A seasonal pack ice study for the Labrador Sea is planned for winter 1980-81.

C-CORE's Radar Group is involved in two HF radar applications. They are participating with the Communications Research Centre, Ottawa, in a skywave project to sense ocean conditions, and a proposal has been prepared to transfer to Canada the technology of ground wave systems for spatial current mapping and their evaluation and development for sea ice and iceberg detection. C-CORE has been active in the development of marine research equipment, recently including a seabed photography system, a submersible diamond drill core, and a timelapse camera control system. A company, INSTRUMAR Limited, was formed to manufacture and sell equipment developed by C-CORE and to undertake prototype development work for the ocean industry.

(b) Department of Physics

The Department of Physics initiated in 1979 a program of study leading to an M.Sc. in Physical Oceanography. Six students have been admitted to the program. A Ph.D. program is being planned for the near future. Research is focused mainly on the Physical Oceanography of Newfoundland and Labrador waters. However, studies are also being

carried out in numerical modelling, ocean mixing processes, ocean acoustics and Arctic oceanography. The elastic properties of natural ice (lake, sea and glacier) are being studied in the laboratory using Brillouin Spectroscopy techniques.

The Physical Oceanography research group is a component of the recently formed Newfoundland Institute for Cold Ocean Science (NICOS). The purpose of this Institute is to foster interdisciplinary academic programs and to co-ordinate and promote the development of scientific knowledge related to the development and exploitation of the cold oceans of importance to Newfoundland and Labrador.

Ongoing research:

- Elastic properties of natural ice (Kiefte, Clouter, Denner and Gammon)
- Ice dynamics in the Labrador Sea (Denner, Keliher)
- Numerical and theoretical studies of coastal circulation dynamics (Helbig)
- Acoustical studies of ocean processes (Denner, Hay)
- The physical limnology and dynamics of large lakes in Newfoundland (Denner, Weir, Wright)

2. Dalhousie University

(a) Chemical Oceanography

R.M. Moore has been working on trace metal distribution in the central Arctic Ocean and on the trace element requirements of oceanic plankton. P. Egli-Stoffyn is investigating the reactions that control the concentration and distribution of dissolved Al and SiO₂ in interstitial waters of recent marine sediments from various environments.

P.J. Wangersky has continued in the development of his model of population growth in a universe in which nutrients appear randomly in time and space, and has extended it to the examination of distributions of benthic organisms. The Turbidostat, a device for the culture of phytoplankton at constant population density, has been redesigned to North American specifications. One Unit is now complete, and several more are being built.

M. Gagnon has defended his Ph.D. thesis on the distribution of surface-active materials in estuaries, and J. Painchaud has defended his M.Sc. thesis on the effects of particulate materials on the regeneration of nutrients by bacteria. U. Löbsiger and R. Gershey have completed the experimental work and are writing their Ph.D. thesis on carbon isotope discrimination in phytoplankton and the chemistry of natural surfactants in near-surface waters, respectively.

R.C. Cooke has followed his interests in the global CO₂ system, the reactions of gaseous, dissolved, and solid inorganic and organic carbons in the sea, the populations and behaviour of small bubbles in aqueous systems, and the physics and chemistry of small systems at interfaces in the environment. Six papers were published during the year in these topics.

(b) Physical Oceanography

Research continues on a number of topics, mainly to do with shore processes or the oceanography of the continental shelf, but with interests also in general surface wave and mixing problems of the deep ocean. Close ties with Bedford Institute continue, in collaboration projects, in the service of B.I. scientists on student committees and in frequent exchanges of ideas. However, as members of the Canadian oceanographic community we are dismayed by the way in which many Canadian research efforts are weakened by the failure of different government departments to consult each other or cooperate, and by the government policy which seems to require a compartmentalisation of work by industry, government and universities. This policy seems to have a particularly adverse effect on the quality of work done on problems of environmental impact.

Some specific research problems at Dalhousie:

- (i) The oceanography of banks and seamounts is being studied by John Loder, Dan Wright and Barbara-Ann Juszko, aided by a strategic grant from NSERC to Chris Garrett. Loder completed his Ph.D. thesis studying many aspects of tidal mixing and rectification. Application of his theories to Georges Bank accounts for many observed features. Work continues on depth-dependent rectification theories, temperature and nutrient budgets, frontal dynamics and mixing. So far the studies have been largely theoretical and related to existing data. Experimental work to test the theories is being planned for 1981 and 1982. Rick Marsden will join the group in January 1981.
- (ii) Research on the flow through Belle Isle Strait continues, through the examination of historical data on currents, sea level and meteorological forcing and with a joint program with Bedford Institute in which current meters and tide gauges were deployed in the Strait from July to October 1980. The project involves Brian Petrie (B.I.), Chris Garrett, Bechara Toulany and Barbara-Ann Juszko who is estimating nutrient fluxes through the Strait, using data obtained on the July and October Dawson cruises as well as historical data.
- (iii) K. Drinkwater continues his analysis of current meter and thermistor chain data from St. Georges Bay, and finds a rapid response to meteorological forcing followed by a slow decay. A two layer baroclinic numerical model is now running and being related to observations.
- (iv) Jerry Smith completed his Ph.D. thesis on waves, currents and Langmuir circulation, showing particularly that, contrary to WKB predictions, waves are not likely to be steeper in the convergences of Langmuir cells.
- (v) The Belle Isle Strait program is stimulating an interest in the oceanography of straits in general, and in the use of sea level data. Keith Thompson will join the group in January 1981 to conduct an AOL funded study of North Atlantic sea level variability on time scales of one month or longer, relating it to meteorological and hydrographic data. Garrett and Toulany have been examining further the sea level changes in the N.E. Gulf of St. Lawrence, and exploring the use of the eigen-functions of the cross-spectral matrix as a guide to the physics.

(vi) Peter Holloway completed a study of the Bay of Fundy as a one-dimensional vertically mixed estuary. A time-dependent numerical model could only reproduce observed salinity patterns with a horizontal diffusivity much larger than can be attributed to shear dispersion, and probably associated with tide-induced residual eddies.

(vii) G. Symonds and D. Huntley have continued to study the interaction between incident waves and offshore bar systems of the kind typically found in the Southern Gulf of St. Lawrence. The research centres particularly on the existence of low frequency motion observed as an important part of the velocity field in previous field measurements. An extensive field measurement programme in August/September 1980 has provided high resolution measurements of the horizontal velocity field over a bar system on the north shore of P.E.I. during storm and calm conditions. The data are being analysed to determine the spatial and temporal characteristics of the low frequency motion. A theoretical model for the forcing of low frequency motion by breaking of incident waves of varying heights has been developed, with analytic solutions for linearly sloping beaches. Numerical solutions have been calculated for the field beach and are being used in the interpretation of the field data.

(viii) D. Huntley has continued to study the low frequency components of data from the first Nearshore Sediment Transport Study on Torrey Pines Beach, California. The results allow a direct comparison of the changing edge wave response as the incident wave energy varies from day to day. This comparison reveals several unexpected characteristics of the incident/edge wave interaction. For example, there appears to be a separation of edge wave modes into distinct frequency bands; this may be due to a bimodal directional spectrum of incident waves refracted around offshore islands.

Tony Bowen is on sabbatical leave at the Departments of Oceanography and Geology, Oregon State University, during 1980/81.

3. Bedford Institute of Oceanography

(a) Ocean Circulation

The air/sea interaction program continues with participation in the second successful field program to study the heat budget of an arctic polynya; this is a joint undertaking with IOS, Sidney, B.C. and AES, Downsview. Analysis of earlier work from the BIO stable tower continues with publication of the main results on drag coefficients and heat flux formulas for high winds. Bulk aerodynamic formulae were used to evaluate the mixed layer heat budget in the vicinity of OWS Bravo and to explain the observed variation in heat storage. A computer model was used, with some success, to obtain air and water drag coefficients for icebergs using data available from offshore oil rigs. The studies on oceanic microstructure continued with the analysis of data collected earlier during the JASIN experiments and with further analysis of the relationship between dissipation in the mixed layer and wind forcing.

We continue to have an extensive and active deep sea oceanography program. Analysis of data on the formation of Labrador Sea Water progressed to the publication stage for the 1976 data set. The description of this process includes the formation of a large, 200 km, gyre with shortlived mesoscale plumes at the boundaries. The summary of oceanographic conditions at OWS Bravo over the years 1967-1971 was completed with the identification and explanation of multiyear trends in

deep winter cooling. From an analysis of current meter data and CTD sections in the Labrador Current, 3-10 day variability indicated the presence of topographic Rossby waves and identified additional restraints on obtaining accurate mean transports for the Labrador Current. The long-term, i.e. ten-year, monitoring program of the Labrador Current at Hamilton Bank continues with two cruises and the preparation of atlases. A diagnostic model for the Labrador Sea with an open-boundary condition was finalized.

The studies of the Gulf Stream and North Atlantic Current were maintained at a level similar to past years. Analysis of the 50°W current meter array continues and another array at 42°W is presently in place intended for a year-long study. This latter program is being coordinated with a larger program at the Woods Hole Oceanographic Institution. A major study of the deep waters of the Newfoundland Basin began in late 1980 with an initial array and CTD survey. This experiment will continue on to the end of 1981. The work on the Flemish Cap continues with the analysis of earlier mooring data, deployment of Lagrangian drifters and seasonal CTD surveys.

The group continued its theoretical work on three dimensional tidal currents. This analysis was used to predict mean flows around banks on the continental shelves. A numerical model of the Gulf of St. Lawrence estuary system was developed in order to predict mean flows and response times associated with the annual fresh water pulse. Some progress was made in the understanding and developing of the theory of solitary waves in the ocean.

Considerable effort was given to the numerical study of the flow in a rotating annulus with differential heating on the horizontal boundaries and to the study of symmetric baroclinic instabilities in an enclosed rotating fluid.

(b) Coastal Oceanography

The results of the Scotian shelf break dynamics current and mass field observations have been analyzed to yield an increased understanding of low-frequency processes occurring at the continental shelf break and slope. Significant progress has been made in measuring and interpreting the effect of low-frequency waves radiated when Gulf Stream rings impinge on the continental rise and in understanding the seasonal and transient aspects of wind forcing, and the importance of these phenomena with regard to deep oceanshelf water exchange. The field program on the Scotian Shelf off Cape Sable is nearing completion. This study is intended to quantify seasonal water transport into the Gulf of Maine and the influence of other low-frequency motions. Field studies in the Belle Isle and Avalon Channels have been completed using arrays of current meters and on-shore and off-shore gauges; the investigation is examining annual and interannual mass transport. Analysis of the Davis Strait Labrador Shelf water mass has continued; monthly charts of salinity/temperature distributions will be compared with estimates of fresh water run-off. The seasonal impact of fresh water may play an important role in regional productivity.

Field observations in the Saguenay Fjord and near the mouth of the St. Lawrence Estuary have contributed substantially to our knowledge of the physical processes in these regions. Analysis of the data collected is expected to result in a better understanding of the dynamics and driving forces in these active areas. Studies of the role of fresh water discharge into the Gulf of St. Lawrence utilize a time-dependent numerical model and historical salinity, temperature and wind data; deep flow in the Laurentian Channel has been monitored at five locations for the past two years. The need for more winter data in the Gulf is

apparent. The numerical model of tides in the Bay of Fundy - Gulf of Maine region has been improved and applied to various problems in waste disposal and sedimentation; the effects of tidal power barriers are being assessed.

Work on wave climate studies continued with the completion of a three-year climate for the eastern Canadian coast and Labrador Sea and ten-year climate for the edge of the Scotian Shelf. Significant multi-year trends in the annual averages were observed. A study of surface water movement using Lagrangian drifters has continued and a broad program has been initiated to improve the capability to track and predict the movement of oil on the Continental Shelf. The behaviour of suspended particulate matter has been studied and the importance of organic matter in flocculation and settling under various conditions has been examined in the laboratory. Sediment data have been collected in the Saint John region to determine the relative roles of natural processes and the dispersal of dumped dredge spoils. Seabed drifters are used to study the dispersal of dredge sediments at the major dump sites in the maritimes region. We are publishing the accumulated data in an Atlas form and it is being interpreted.

(c) Chemical Oceanography

Studies of the behaviour and transport of trace metals in estuaries, coastal waters and the open ocean have continued. Most of the effort in 1980 involved the examination of the distributions of suspended particulate material and dissolved and particulate metals in the Northwest Atlantic Ocean. Refinements were also made in the models we originally developed to estimate the fluxes of metals through the Gulf of St. Lawrence. These have allowed us to examine the seasonal behaviour and fluxes of both inorganic and organic particulate matter, trace metals and nutrients in this system and to draw some conclusions about the generic features of coastal zone transport. We also assisted the Intergovernmental Oceanographic Commission in the conduct of a sampling intercalibration to assess the biases introduced by differing seawater sampling procedures for trace metals.

Sources, sinks, and the distribution of organic carbon in the St. Lawrence Estuary have been examined by stable carbon isotope ratio analysis of various organic and inorganic carbon samples collected in August-September, 1979. Stable carbon isotope methods have been used to study the sources and behaviour of organic matter in the Eastern Canadian Arctic and to study the relative importance of different potential organic carbon sources to the Pecks Cove Mudflat Ecosystem in Bay of Fundy. An exploratory study using stable carbon isotope ratio method to study the food chains in Scotian Shelf ecosystem is being carried out in collaboration with a scientist at Dalhousie University. Further work on oxygen isotope sea ice meltwater studies in the Eastern Canadian Arctic are being carried out with ice water samples collected in 1980 to examine the year-to-year variations in sea ice meltwater distribution and the extent of melting of glacial ice. An experiment to determine the variability and isotopic equilibrium behaviour of a living benthic foram species (*Hoglundia elegans*) separated from box core samples in Newfoundland slope is being carried out in collaboration with a scientist at the Atlantic Geoscience Center with a view to studying the paleoclimatic changes during the late glacial and Holocene time.

Considerable research effort has been concentrated in northern waters, particularly Baffin Bay. Nutrient distributions have been used to identify some of the water masses in the area and recent measurements of nutrients in both the water column and sediment pore waters are intended to be used to address some questions related to nutrient regeneration processes. Water samples for Cesium-137, Strontium-90, and

tritium analysis were collected at selected depths in Baffin Bay to complement earlier tritium data. These measurements are expected to throw more light on the processes and rates of water exchange in the region. Alkalinity and total inorganic carbon measurements have been interpreted to show evidence of the oceanic build-up of carbon dioxide as a consequence of fossil fuel combustion. They have also enabled estimates of the thickness of sea-ice turnover in Baffin Bay to be made.

Research in marine pollution has also continued its focus on the Canadian Arctic with particular reference to natural seepage of petroleum from the Baffin Island continental shelf. Studies of the hydrocarbons in the water and sediments, using a variety of analytical techniques including gas chromatography/mass spectrometry, have proven that seepage is occurring at Scott Inlet and Buchan Gulf and that the general background in Baffin Bay is derived primarily from atmospheric fallout of products of high-temperature combustion. A great deal of effort was also devoted to the interpretation of the results of the IOC/WMO Marine Pollution Monitoring (Petroleum) Pilot Project and to other international activities related to marine pollution.

Measurements of fallout radionuclides and their stable analogues continued in dissolved, suspended particulate, and sediment phases in the Bay of Fundy in accordance with the pre-operational monitoring program established for the Point Lepreau Nuclear Generating Station.

In an extensive study of surficial sediments collected within the Gulf of St. Lawrence and its associated waterways, the proportion of land-derived organic matter was found to be high in the Saguenay and Humber River fjord systems, but decreased to levels typical of oceanic marine sediments in the open Gulf. The Gulf of St. Lawrence is not dominated by terrigenous inputs of organic matter; most of the organic matter in the sediments is produced by in situ production.

In addition to the measurement of C/N and $^{13}\text{C}/^{12}\text{C}$ ratios of the organic matter in recent sediments, which give some general information as to the origin of organic matter (whether terrestrial or marine), we have used lignin as an indicator of the contribution of unambiguously terrigenous organic matter in coastal sediments.

Sediment-depth profiles of Pb-210 and Cs-137 in sediments in the Saguenay Fjord have been used to resolve the seasonally-modulated component in sedimentation rates which is related to enhanced rates of particle transport during the high spring river discharge. These results have been used to determine rate constants which characterize both particle erosion rates from the drainage basin and rates of transport through the water column from fresh water to marine environments.

(d) Ocean Technology

Equipment is being acquired and assembled into systems for the measurement of physical (conductivity, temperature, dissolved oxygen, etc.) and biological (chlorophyll, zooplankton, light attenuation, etc.) parameters in the ocean. This includes development of new and faster sensors for CTD's and the Batfish, construction of a profiling pump system, and studies of the use of light transmittance for estimating suspended solids in admixture with chlorophyll and dissolved organic matter. Attention is being given to the dynamics of CTD cables and instrument packages and shipboard handling systems for this equipment. Improved methods of handling long electromechanical cables are also being developed. Studies of corrosion problems and motion of current meter moorings are underway. Applications of acoustics and signal processing techniques to the improvement of echo sounding methods and location of oceanic microstructure and biota are being explored.

The Division is concerned with bottom sampling techniques including modifications and improvements to an electrically-powered hard rock coring drill to extend its ability to sample a wider range of rock types and its depth of operation, and provision of an acoustic positioning system aboard ship to improve site selection and relocation capabilities. Research is also underway on acoustic positioning methods in the solution of oceanographic and geological problems. The BIONAV integrated navigation system is now operational. Further work has been done on an acoustic current profiler with the aims of improving descent/ascent rate control, increasing position resolution, and establishing the accuracy of position computations by verification against an independent measurement of profiler depth.

4. Université du Québec à Rimouski: Département d'Océanographie

Programmes de recherche en géochimie et en physique à l'UQAR.

(a) Ce programme de recherche inclut messieurs J. Lebel, N. Silverberg, B. Sunby et leurs étudiants et vise à comprendre et quantifier les processus géochimiques et les flux à travers les interfaces eau-sédiment et eau douce-eau de mer. Parmi les études en cours, nous citons: les processus chimiques à l'interface eau douce-eau de mer dans l'intervalle 0 à 1% S; la relation entre la taille des particules et leur composition chimique; la diagenèse des éléments de transition; l'influence des animaux benthiques sur la biogéochimie des sédiments; les paramètres géologiques et biochimiques des sédiments du chenal Laurentien; la mesure directe des vitesses de sédimentation; la mesure des flux d'espèces élémentaires vers le sédiment; la mesure des flux d'espèces dissoutes provenant des sédiments et la diagenèse du soufre et ses effets sur les cycles géochimiques des métaux de transition.

(b) Au cours de l'année 1980, nos recherches en océanographie physique menées par M.I. El-Sabh et ses collaborateurs et étudiants gradués se sont poursuivies dans l'estuaire de Saint-Laurent et la partie nord-ouest du golfe Saint-Laurent. Nos travaux ont porté sur l'interprétation des données des courants recueillies simultanément à dix endroits différents entre Pointe-des-Monts et Pointe-au-Père, de mai à septembre 1979. Ces données serviront, entre autres, à étudier la dynamique de la circulation (M. El-Sabh), à calculer le transport de masses d'eau entre l'estuaire maritime et le golfe (V.G. Koutitonsky et M. El-Sabh), à étudier les processus du mélange longitudinal et transversal de masses d'eau dans cette région (M. El-Sabh, V.G. Koutitonsky et P. Larouche). Une étude théorique des mouvements résiduels engendrés par la marée dans l'estuaire maritime du Saint-Laurent (T.S. Murty et M. El-Sabh) a donné des résultats qui correspondent bien qualitativement avec les observations. Un modèle bi-dimensionnel a été utilisé afin d'étudier et de simuler la circulation verticale engendrée par la marée dans l'estuaire du Saint-Laurent (C. de Borne de Grandpré et M. El-Sabh). Les résultats de ce modèle mettent en évidence des phénomènes physiques caractéristiques de l'estuaire et qui ont été plusieurs fois observés, tels que les marées internes, la remontée d'eau profonde et les effets des gradients horizontaux de salinité sur les profils verticaux de vitesse. Une étude descriptive des amplitudes des ondes de tempête et leurs interactions avec la marée dans la côte est du Canada, et en particulier dans l'estuaire du Saint-Laurent, a été effectuée par J.-M. Briand, T.S. Murty et M.I. El-Sabh. Finalement, les résultats obtenus de l'étude du courant de Gaspé (J. Benoît et M. El-Sabh), menée en coopération avec C.L. Tang, ont été utilisés afin d'étudier les interactions de la dérive de la population de larves de poissons avec l'environnement physique dans ce système de hauts niveaux de production biologique (M. El-Sabh, M. Sinclair et Y. DeLaFontaine).

5. Pêches et Océans, Sciences et levés océaniques: Région du Québec, Québec (Québec)

(a) Océanographie chimique

Le programme est sous la direction de D. Cossa de l'INRS-Océanologie de Rimouski, maintenant avec Pêches et Océans à Québec en vertu d'un programme d'échange. L'ensemble des projets de recherche est surtout axé sur l'étude de la pollution marine. En 1990, en plus de poursuivre les analyses de métaux en traces dans divers échantillons d'eau, d'organismes et de sédiments provenant du Saguenay, de l'estuaire et du golfe du Saint-Laurent, une campagne a été réalisée dans l'estuaire moyen afin d'étudier la géochimie du mercure dans la zone de turbidité. L'étude de la moule bleue comme indicateur de pollution dans l'Estuaire et le Golfe s'est également poursuivie, non seulement pour les métaux mais aussi pour les hydrocarbures polycycliques aromatiques (HPA). Un rapport global sur ce projet a été préparé. Enfin, la distribution des HPA dans les sédiments de fjord du Saguenay a fait l'objet d'une étude.

Sur le plan international, le groupe a continué de prendre part à plusieurs exercices d'intercalibration de métaux en traces, particulièrement dans l'eau de mer. De plus, un scientifique du groupe (D. Pouliot) a participé à une nouvelle phase de l'expérience sur l'oxydation du manganèse en eau de mer, menée par K. Kremling (Meereskunde, Kiel, RFA) et C.S. Wong (I.O.S., Sidney, B.C.). Enfin, D. Cossa a travaillé avec les chercheurs de l'Université Pierre et Marie Curie à Paris sur la détermination de HPA dans les sédiments marins.

(b) Océanographie physique

Ce programme a débuté seulement au milieu de 1980 avec l'arrivée d'un scientifique (S. Peck). Toutefois, on a déjà commencé l'acquisition de l'équipement de base essentiel, et un projet sur l'influence du débit des rivières sur le milieu marin côtier dans le nord du Golfe a été entrepris par une campagne de mesures en mer dans la région située au nord de l'île d'Anticosti.

(c) Océanographie biologique

Le programme, sous la direction de J.C. Therriault, vise à obtenir une meilleure connaissance globale des mécanismes et processus dynamiques qui contrôlent la production biologique des divers niveaux trophiques dans les habitats marins côtiers en général et en particulier dans les systèmes estuariens. Le thème de recherche principal porte sur la variabilité estuarienne de la productivité et sur les facteurs physiques et chimiques qui pourraient l'influencer.

En 1980, les campagnes d'échantillonnage mensuelles à un réseau de 30 stations dans l'estuaire maritime du Saint-Laurent se sont poursuivies dans le but d'étudier la variabilité temporelle et spatiale à grande échelle de la productivité primaire et secondaire. En outre, plusieurs projets conjoints avec les chercheurs du GIROQ et d'autres universités ont porté en particulier sur l'étude de la variabilité à petite échelle à une station pilote, sur la variabilité temporelle de la biomasse phytoplanctonique dans une zone littorale estuarienne, sur la comparaison de la succession phytoplanctonique entre les zones pélagique et littorale, sur le phytoplancton des glaces de l'Estuaire et sur les processus hétérotrophiques dans l'Estuaire moyen. Enfin le rapport final d'un projet conjoint avec la Région du Québec de la Gestion des Pêches du ministère, sur le homard des lagunes des Iles-de-la-Madeleine, a été préparé.

6. GIROQ - Groupe Interuniversitaire de Recherches Océanographiques du Québec

Le GIROQ regroupe des chercheurs des universités McGill, Laval et de Montréal. En 1980, les activités du GIROQ en sciences physiques se sont déroulées dans le cadre des études menées dans l'estuaire du Saint-Laurent et dans les baies de James et d'Hudson.

Estuaire du Saint-Laurent

- Analyse de la variabilité à long terme des caractéristiques des masses d'eau et de la circulation dans l'Estuaire maritime, principalement à la tête du chenal Laurentien, à proximité de l'embouchure du Saguenay. (R.G. Ingram, McGill)
- Etude de la dynamique des fronts à petite échelle. (R.G. Ingram, McGill)
- Etude des échanges quantitatifs entre l'Estuaire et le Saguenay. (Pêches et Océans Canada en collaboration avec R.G. Ingram, McGill)
- Etude de la variabilité de la circulation hydrodynamique dans l'Estuaire moyen supérieur. (Y. Ouellet, Laval)
- Détermination de la circulation résiduelle à différentes profondeurs dans l'Estuaire moyen inférieur, en relation avec le transport des larves de poissons. (C. Anderson et R.G. Ingram, McGill)
- Développement d'un système de mesures pour l'étude de la couche suprabenthic dans l'estuaire du Saint-Laurent. (B. d'Anglejan et R.G. Ingram, McGill)
- Etude des mécanismes de transport de sédiments dans la couche suprabenthique dans l'Estuaire moyen. (J.P. Savard et B. d'Anglejan, McGill)
- Etude des interactions entre le polychète *Pista maculata* et son substrat sédimentaire dans l'Estuaire moyen. (J. Daignault et B. d'Anglejan, McGill)
- Formes du phosphore dans la matière particulaire et les sédiments. (M. Lucotte et B. d'Anglejan, McGill)

Baie de James

- Etude des caractéristiques des masses d'eau et de la circulation dans l'estuaire de la rivière Eastmain et à son embouchure dans la baie de James et effets de la réduction des débits d'eau douce. (R.G. Ingram, McGill)
- Etude du régime sédimentaire de l'estuaire de la baie du Rupert et de la Rivière Eastmain. (B. d'Anglejan, McGill)

Baie d'Hudson

- Etude de la circulation et des caractéristiques des masses d'eau du détroit de Manitounuk et des embouchures de la Grande rivière de la Baleine et de la Petite Baleine (Sud-est de la baie d'Hudson). (R.G. Ingram, McGill)

7. McGill University: Marine Sciences Centre

(a) Physical Oceanography

Field study and modelling of the Eastmain River (James Bay) for both open water and ice-covered conditions. Detailed survey of modification to estuarine circulation and salt intrusion characteristics following major reduction of fresh water input from July 1980 onwards. (R.G. Ingram)

Further studies of the cross-channel front formed near Ile Rouge in the St. Lawrence estuary. From moored current meter records and profile data along transects taken in May 1980 conditions suitable for frontogenesis and frontolysis were determined. Intensity of cold-water upwelling and cross-channel tidal flow were found to be most important in explaining frontal phenomena. (R.G. Ingram)

Studies of estuarine circulation and mixing in the Great Whale River, Manitousuk Sound, and the upper portions of the St. Lawrence River were continued in 1980. Emphasis was placed on data analysis of current meter and STD records obtained in previous years. (R.G. Ingram, C. Anderson, S. de Margerie)

Ice Research: No field work was undertaken in the period September 1979 to December 1980. The year was devoted to the analysis of physical oceanographic data collected on AIDJEX (1975-76), in Barrow Strait in 1977 and 1978 and on LOREX 79. (E.R. Pounder, M.P. Langleben)

(b) Marine Geology (B. d'Anglejan)

A benthic system to monitor in situ the fluctuations of suspended sediment concentrations (turbidity) near the seabed, in response to changes in tidal velocities, winds, and run-off has been developed. It consists of an attenuation meter and a current meter with S, T, and P sensors, both recording on magnetic tapes. Calibration of the attenuation meter showed good correlation with particle concentrations in the range observed. The system gave several weeks of continuous data at a 20-meter station in the St. Lawrence estuary in June and July.

A study of the partition of phosphorus between various chemical phases in sediments and seston has been initiated on material collected in the St. Lawrence upper estuary. A sampling program was carried out in the estuary on both north and south tributaries for this purpose. The analytical procedures used allow to distinguish between absorbed iron hydroxide bound and "apatitic" phosphate, as well as the relative proportions of total inorganic to organic phosphorus in the sediments. The proportion of easily available phosphate in surface sediments can be estimated.

A sedimentological study of the Eastmain estuary (James Bay Territory) was undertaken early last summer as a baseline study to determine in the coming years the effects of river cut-off (which took place in June, 1980) on its sedimentation regime. A large collection of gravity cores, seston samples, shallow reflection seismic profiles and current velocity observations was obtained. Further field work is planned for next summer.

8. Ocean and Aquatic Sciences: Central Region, Burlington, Ontario

(a) Oceanography

Physical and biological oceanographic studies are continuing in Hudson and James Bays to assess the effect on the marine environment due

to freshwater regulation brought about by ongoing and planned hydroelectric development in the surrounding watershed. In February and March, 1980 a physical and biological oceanographic survey was carried out in James Bay off the La Grande River to obtain physical measurements under an increased river discharge condition and to examine the effect of the plume on the distribution of nutrients and biota. A tidally averaged integral model is being developed to examine the role of riverine entrainment in the near-field and tidal mixing in the far field on plume dispersion (N.G. Freeman). A vertical one-dimensional surface mixed layer model is being applied to Hudson Bay observations to investigate the effect of wind and tidal energy, and surface salt and heat fluxes on the formation and deepening of the seasonal pycnocline (S.J. Prinsenberg). Through the use of integrated numerical modelling and stochastic filtering techniques significant improvements have been achieved in the accuracy of water level predictions and the estimation of friction factors from observed data in Chesterfield Inlet (W.P. Budgell). Working with J.C. Roff at the University of Guelph, nutrient biomass fluxes in the long, narrow, partially mixed Chesterfield Inlet estuary were calculated and estimates of net production and nutrient uptake will be made by calculating differences from the conservative condition for nutrients (N.F. Watson).

A PhD thesis (University of Southampton) investigated the physical processes controlling circulation in the middle estuary of the St. Lawrence River, and examined the influence of tidal advection of horizontal density gradients on fixed point time-series measurements (L.R. Muir).

In the central arctic, work centred around the processing of current meter and CTD data collected in the spring of 1979 in Sverdrup Basin (G.S. Peck). Dr. Bert Bennett, formerly a senior oceanographer with PetroCan joined the group late in the year as arctic oceanographer. In March and April 1981, a physical oceanographic survey is planned for Barrow Strait to test instrumentation and mooring technology for long-term measurement of transport and biological variability in Arctic channels.

(b) Ocean Technology

An unmanned through-the-ice current profiling system was developed and deployed successfully in the winter field program, and is presently being expanded to include gyroscopic orientation for arctic measurements (S.D. Baird). Work is continuing on an interactive graphics package for editing of Aanderaa current meter records (C. Doekes). Equipment and methods are being developed for the installation and retrieval of fixed orientation current meter moorings through-the-ice (D. Brooks). During 1980, work continued on the development of solar assisted power systems for powering of Arctic instrument and survey systems (R. Coons & E.O. Lewis). The Ice Radar Program which is attempting to remotely classify ice type utilizing a modified marine radar continued with a field experiment in Lancaster Sound and data analysis at the Communications Research Lab of DOC. A start was made on defining an ice physics program to be carried out in concert with the regional oceanographic activity (E.O. Lewis).

(c) Shore Properties Studies

Data collected from 162 erosion stations established eight years ago, along the erodible Canadian Great Lakes Shore, was computer processed and further analyzed to enable assessment of the rates and processes of erosion and sedimentation. Together with these measurements, other valuable information such as coastal zone land use changes, as recorded periodically on sequential oblique aerial colour

photography, soil composition and vegetation inventories provided temporal and spatial data sets over time periods of sufficient length that are useful in the detection of significant changes in environmental variables (W. Haras).

An Interim Report on the Erosion Monitoring Program examined the seven years of data collected to date, provided an assessment of the nature and degree of erosion for different shore types and recommended modifications in data collection for the next five years of the program (G. Boyd).

(d) Environmental Assessment

Technical reviews of offshore hydrocarbon drilling applications and respective contingency plans, were carried out, including: the Arctic Pilot Project Environmental Statement; Panarctic's applications for exploratory drilling in the Sverdrup Basin; future exploratory drilling in Hudson Bay; and Canada's new Oil & Gas Production Regulations (J.R. Shaw).

9. National Water Research Institute, Burlington

Physical limnology research at the National Water Research Institute concentrates on five areas:

- physical limnology of large lake systems with particular emphasis aimed at better quantitative understanding of physical processes and the application of this knowledge in developing hydrodynamic and transport numerical models.
- physical limnology of special lake systems such as fjords and reservoirs.
- studies on coastal and shore dynamics to investigate nearshore waves, currents, diffusion, sediment movements, and shore development.
- studies of air/water interaction including the generation, propagation, and dissipation of wind-waves, and interfacial momentum, mass, and heat transfer.
- studies of instrumentation used in physical limnology and meteorology.

10. Fisheries & Oceans, Ottawa: Marine Sciences and Information Directorate

The Marine Sciences and Information Directorate carried out its national and international functions and responsibilities through its three branches: Ocean and Aquatic Science Affairs Branch (OASAB), Marine Environmental Data Service Branch (MEDS), and the Scientific Information and Publications Branch (SIPB).

OSAB played a role in the production of policy guidance papers for OAS in fields such as ocean climate, Arctic marine science, marine transport, and ocean information services during the year. In addition, there was an increased role in the coordination of advice to regulatory agencies such as DOT, DINA, and DEMR. Activities during the year included:

- participation in the Environmental Assessment and Review Process on the Arctic Pilot Project;
- involvement in national issues such as Long Range Transport of Atmospheric Pollutants, the Canadian Climate Program, Arctic oceanography, and offshore drilling requirements;
- completion of a bibliography on Northern Sea Ice; and

- establishment of remote sensing priorities for DFO and staffing of the Remote Sensing Coordinator's position.

The Marine Environmental Data Service is the branch of MSID responsible for archiving marine data. MEDS is Canada's national marine data center, archiving oceanographic data collected in the ocean areas around Canada, including the Northeast Pacific, Arctic, and Northwest Atlantic Ocean north of 35°N latitude. Present holdings cover physical data (such as bottle, BT, STD/CTD, tides, water levels, and wave rider) and some chemical data. As a forerunner to long-term plans to expand holdings to include more chemistry, biology and pollution data, MEDS is rapidly developing a national inventory system to track all oceanographic data sets of interest to Canada, both of Canadian origin and data collected by other countries in the area. The system is called CAMDI, the Canadian Marine Data Inventory.

A considerable part of MEDS effort is to retrieve data from its archives on request largely by Canadian technical and scientific users, but also to a limited extent for foreign nationals. MEDS has developed, over the years, a number of data services and products which provide the requester with data in a form and format well suited to his individual need.

The development and improvement of international data exchange mechanisms is an ongoing priority with MEDS. For example, MEDS is participating in NAFO as the regional data centre for the organization. This participation requires support for the Flemish Cap Project as well as analyses of historical oceanographic data from the east coast of Canada to attempt to establish baseline conditions. Also, the FGGE program of last year was completed and an atlas containing all of the products generated by MEDS is presently being compiled, and soon to be published. Various other smaller international initiatives are also underway.

Dr. Godin continued his liaison with the CICESE in Ensenade, Mexico by semi-annual visits in support of theses work and as follow-up to the preparation and publication of two joint papers.

The Scientific Information and Publications Branch (SIPB) publishes most and indexes all Fisheries and Oceans scientific publications. It also abstracts and indexes all Canadian literature relevant to Aquatic Sciences and Fisheries Abstracts, which is available in Canada either in hard copy or as an online database searchable through the QL retrieval system. The database adds over 20,000 references annually and covers all aspects of ocean science and technology.

During 1980, approximately 700 publications were issued including 176 mechanical reports, 100 data reports, 93 manuscript reports, 139 studies and 175 reports in the translation series.

11. University of British Columbia: Department of Oceanography

(a) Physical Oceanography

T.R. Osborn is pursuing his work on ocean turbulence, particularly on measurements and interpretation of small-scale fluctuations of velocity shears. Measurements over the continental slope off Vancouver and in the North Pacific Subtropical Front north of Hawaii (as part of the FRONTS experiment) were performed by a Research Associate, R.G. Lueck. A new profiling vehicle, CAMEL III, is being developed by Jim Moum; it will feature internal data recording and will have a greater depth capability (3000 metres). Development also continues on a small-scale velocity profiler which will allow denser sampling in time and space and be deployable in rough weather. Turbulence measurements have also been made from the U.S. submarine Dolphin and show promise for making horizontal transits through the ocean.

S. Pond used his profiling system (Temperature and Salinity to 10 m every 20 seconds) in the Fraser River plume in June. Drogue tracking to measure the upper layer flow (4 levels in top 5 m) was also done. Two cyclesondes (internally recording profiling current meter/CTD systems) were deployed in Alberni Inlet for 3 months this summer and one in Knight Inlet for 3 days. They will be deployed in the central Strait of Georgia in February 1981 for four months and then in Knight Inlet for two weeks.

W. Large, on a post-doctoral year under S. Pond, analyzed the JASIN data for moisture and sensible heat flux coefficients. A note was written up in JASIN NEWS. Further measurements have just been obtained on the Parizeau during STREX; they extend the range of wind speeds for which moisture flux coefficients can be estimated to about 35 knots. R. Marsden completed his Ph.D. on methods of modifying bulk aerodynamic parameterizations for estimating fluxes from synoptic and climatological data.

J. Dewar and W.J. Emery have completed computations of TS and SZ curves; an atlas of mean TS, SZ and TZ curves for the North Pacific and North Atlantic oceans is in preparation; it will be published by Pergamon Press in "Progress in Oceanography" as well as a separate hardbound volume. W.J. Emery is also analyzing the 3-D spectra of surface winds and temperature (with a Ph.D. student at Texas A & M). A paper on the generation potential of sea surface temperature variations at Rossby wave scales has been submitted to J. Physical Oceanography.

In the spring of 1980 a multi-ship XBT survey was made in the frontal region northeast of Hawaii using four Canadian Forces vessels. Based on the success of this survey (which revealed an interesting small eddy feature) additional surveys are planned for 1981 deployments of west coast destroyer squadrons. This work is a cooperative effort between W.J. Emery and D. Krauel of Royal Roads, and is being supported by DREP. Results of an earlier analysis (in collaboration with C. Ebbesmeyer, Seattle) of six XBT multi-ship swathes to identify open ocean eddies have been submitted to J. Physical Oceanography.

In collaboration with E. Carmack (Canada-Inland Waters) and Dan Georgic (WHOI), W.J. Emery is analyzing temperature sections across the Antarctic Circumpolar Current. Two years of data, 1500 casts in 20 sections, together with simultaneous meteorological measurements, will provide an analysis of the heat budget of a portion of the Southern Ocean.

The analysis of near-surface data on temperature and salinity collected from the sea-water intake of ferries crossing the Strait of Georgia is part of the Ph.D. project of Louise Royer, under W.J. Emery. These data, together with monthly cruises and LANDSAT images of the Fraser River plume will help understand the upper-layer dynamics of the Strait of Georgia.

P.H. LeBlond has continued theoretical studies of coastal geomorphology, relating various models of headland-bay geometry and documenting the need for on-offshore sediment transport in coastal erosion models on the basis of the lessons taught by headland-bay beach models. This work was presented at the First Canadian Coastal Conference at Burlington.

S. Aranuachapun and P.H. LeBlond have completed a study of the relation between signal levels on LANDSAT multiple spectral scanner tapes and the turbidity of near-surface waters. The various contributions to the total signal as well as the sources of error have been discussed. The results have been applied to a description of the Fraser River plume and will appear in Remote Sensing of the Environment. In collaboration with I. Perry, S. Aranuachapun has also completed a study of spectral

variations of sea-water irradiance due to phytoplankton pigments, based on data collected along the coast of B.C.

P.H. LeBlond has applied a simple geostrophic dynamics to a two layer system to provide a qualitative model of re-entrant circulation in some of the channels of the Arctic archipelago. Y. Gratton, working with P.H. LeBlond, is pursuing a theoretical study of low-frequency nonlinear interactions in a semi-enclosed basin.

A.E. Hay, working under R.W. Burling, has completed theoretical studies of sound scattering by clouds of suspended particles and used the results to interpret his acoustic sampling of a continuous turbidity current due to tailings disposal in Rupert Inlet.

L.A. Mysak and his collaborators continue work on large scale oceanic variabilities. An analytical barotropic instability model of flow along a trench has been developed; this model has been applied to the Alaskan Stream in an attempt to explain wavelike features observed there in infrared satellite imagery. In collaboration with R. Muench (SAI) and J. Schumacher (PMEL) baroclinic instability models have been applied to Shelikof Strait (between Kodiak Island and the Alaskan mainland). Local current measurements show 2-5 day oscillations in the mean southwestward flow through that Strait. A novel feature of this study is the downstream shift in the frequency of spectral peaks; this is attributed to variations in the bottom topography. With W. Hsieh, the theory of resonant interaction between shelf waves is being tested against data from the Oregon Shelf. A three-layer viscous, wind-forced model has been developed, with G. Mertz, to explain fluctuations (of 10-15 day period) in the source region of the Somali Current. In collaboration with A. Willmot, a post-doctoral fellow, two models of the forcing of trench waves have been developed: boundary current forcing and wind-stress generation - these have been applied to the Japan trench and Aleutian trench respectively. Projects with two other post-docs, W. Perrie and H. Hukuda, involve respectively the development of non-linear equations to describe the flow over an obstruction on the continental slope, and the study of finite amplitude baroclinic instability theory for flow over topography.

(b) Chemical Oceanography

E.V. Grill, in cooperation with R.L. Chase, has been studying sediments from the Juan de Fuca and Explorer Ridge areas, two active spreading centres that lie just off the west coast of Vancouver Island, to determine if metal-rich hydrothermal deposits occur there. A study also is being made by T.F. Pedersen and E.V. Grill on the chemistry of trace metals in the sediments of Rupert Inlet, a fjord on Vancouver Island, where large volumes of mine tailings currently are being discharged from a copper-molybdenum mill. In addition, studies were carried out (E.V. Grill) on the kinetics and mechanism of the oxygenation reaction of manganese in Saanich Inlet, another fjord on Vancouver Island. Finally, the chemical behaviour of manganese within the Fraser River estuary was examined with S. de Mora and E.V. Grill.

R.J. Anderson continued his research on the secondary metabolites produced by marine invertebrates and marine phytoplankton. Two new peptide alkaloids, celenamide C and D were isolated from the burrowing sponge Cliona celata. With J. Hellou, a series of six sesquiterpene hydrocarbons have been extracted from the dorid nudibranch Cadlina leutomarginata and a novel fragrant sesquiterpene from a similar organism, Acantholeris nanaimoensis. With Kirk Gustafson, a dialkyl dioxo-s-triazine metabolite has been isolated from skin extracts of another nudibranch, Triopha carpentaria; in addition, a study of antibiotic and antialgal production by the dinoflagellate Gymnodinium sp.

has been initiated. Rick Stonard has achieved a synthesis of a dehydroamino acid containing portions of the celenamides, with the aim of studying Ca⁺⁺ chelation abilities of these peptides; he has also isolated a nitrogen-containing skin secretion from Onchidoris bilamellata. A post-doctoral fellow, A. Gillam, has been working on the isolation and the structure elucidation of hydroxamate siderophores from axenic cultures of marine phytoplankton. Anderson isolated the defensive secretion onchidal from the pulmonate Onchidella borealis; in collaboration with M. Leblanc and R.A. Catalico (Botany, UBC) a pure oyster larvae toxin has been extracted from the phytoplankton Opisthodiscus Latens. Structural work on that toxin is in progress.

Studies of the geochemistry of oceanic ferromanganese nodules have been continued by S.E. Calvert. An investigation of the rare earth element chemistry of nodules and associated sediments from the Pacific, in collaboration with H. Elderfield of Leeds University (U.K.), has been completed showing further evidence for the role of diagenetic reactions in the formation of nodules and their ultimate composition. In addition, the upper and lower surfaces of discoidal deep sea nodules, previously shown to form by precipitation from sea water and from sediment pore waters, respectively, have distinctly different rare earth element contents. Work on the strontium isotopic composition of nodules and sediments is seeking to identify sources of major and minor elements in the nodules and the origin of the aluminosilicate component of both nodules and sediments.

S.E. Calvert has started an investigation of the trace metal chemistry of the sediments of the inlets along the B.C. coast, with the particular aim of studying the role of organic association and sulphide mineral precipitation in controlling metal concentrations and behaviour in basins having different degrees of hydrographic restriction. New sampling equipment has been developed to collect undisturbed sediment cores which can be sampled at sea.

A review of the sedimentary geochemistry of silicon has been completed for a volume on the Geochemistry and Biogeochemistry of Silicon, edited by S.R. Aston, to be published by Academic Press.

(c) Geological Oceanography

Several M.Sc. thesis projects are underway on sedimentary and trace-element geochemistry of modern sediments from Juan de Fuca and Explorer Ridges, under direction of R.L. Chase and E.V. Grill: M.G. Price concluded that hydrothermal input into muds cored on Juan de Fuca Ridge at 49°N is not discernible; R. Cook found striking correlation between trace-metal contents and clay percentage of turbiditic sediments in northern Juan de Fuca Ridge; theses of K. Hansen and G. Beland are still underway. B. Cousens (M.Sc. candidate) commenced study of basalt from various dredgehauleds on Explorer Ridge under R.L. Chase's supervision.

12. Royal Roads Military College - Coastal Marine Science Laboratory

(a) Water Mass Studies

Circulation and Modelling of Estuaries and Harbours - D.P. Krauel

The study is concerned with the dynamics of estuaries and harbours with special emphasis on circulation, mixing, and water level oscillations. Data sets from the Bras d'Or Lakes, Nova Scotia and the Miramichi Estuary, New Brunswick have been analyzed to determine the relative importance of environmental forcing at various time scales by the wind, freshwater runoff, tides, and barometric pressure. The Miramichi data were used to calibrate and verify a numerical model which

was used to separate the influences of the freshwater runoff and the wind. Additional coliform data from the Royal Roads outfall have been obtained and were used to refine the statistical model of dispersion from marine outfalls. A detailed study of coastal erosion in the vicinity of CFB Comox has been completed with the aid of a computer model and historical aerial photographs. Software for an information archiving and retrieval system based on a Hewlett-Packard 9825 calculator has been improved and other software for data analysis and presentation has been developed.

(b) Sea Bottom Studies

Sea Bottom Studies - Acoustics - P.G. Schurer, H.J. Duffus,
W.T. MacFarlane

An acoustic bottom survey has been carried out in the Victoria/Esquimalt Harbour approaches and in Tsehum Harbour. South of Esquimalt Harbour an acoustic mask is located approximately 5 meters below the sea bottom. The mask is believed to be related to the presence of gas bubbles in the sediment. South-east of the Victoria Harbour entrance a field of "sand waves" was found. This area is used for dumping and currents may have reworked the dumped material into bottom waves. A set of up to seven reflectors in a 3 meter thick sediment band is found close to shore between Saxe Point on the Esquimalt waterfront and Trial Island. The strata may have been deposited from the outwash of retreating glaciers. South of Victoria Harbour the strata are truncated by the sea bottom and are accessible for a coring study. A maximum in the magnetic anomaly can be correlated with bedrock in the sub-bottom. The bedrock outcrops south of Brothie Ledge.

The application of the profiling system in less than 1 meter of water in three different intertidal zones in Tsehum Harbour was successful. The location of bedrock under the sediment could be determined. A penetration into the sub-bottom of approximately 30 meters was achieved.

Sea Bottom Studies - Magnetics - W.T. MacFarlane, J.M. Gilliland,
M.J. Press

Forty-five magnetic profiles roughly perpendicular to the seaward extension of the Leech River Fault have been obtained using a total-field magnetometer towed by R.V. "Tayut" in Royal Roads and the waters off Victoria, from the Coburg Peninsula to Trial Island. Good positional accuracy and straight track lines were achieved using a navigation system based on a Marinav Trisponder system and an on-board Hewlett-Packard 9825A computer.

It appears possible to identify the seaward extension of the Leech River Fault from the raw magnetic data. The fault trace runs parallel to the Esquimalt-Victoria shoreline from Coburg Peninsula to Clover Point, at a mean distance of about 1.7 km. Beyond Clover Point the fault trace continues on a straight-line heading of about 112° True, while the shoreline trends away toward the north-east.

The magnetic pattern displays several offsets perpendicular to the trend of the Leech River Fault, and these offsets seem to be associated with topographic features closer to shore. One such offset is apparently associated with Brothie Ledge, and coincides with a rock outcrop on the fault trace, detected on sub-bottom profiles. Another such offset occurs at Clover Point where the coastline and the fault trace begin to diverge.

(c) Sea Surface Studies

Remote Sensing and Surveillance - M.J. Press, H.J. Duffus, P.J. Schurer

Difficulty in scheduling time on the CCRS Image 100 computer system or on the Pacific Research Center computer has delayed satellite image processing. Lapse rate photography of the Mount Helmcken Marine Traffic Radar display has yielded some good photos showing gyres and tidal fronts. Analysis is proceeding. The wave staff in Royal Roads succumbed to a storm after two months, but three weeks of wave data were obtained.

13. Institute of Ocean Sciences, Sidney, B.C.

(a) Offshore Oceanography

Collection of STD/Hydro data at Station P and along Line P was continued using the weatherships to determine the steric contributions to mean sea level variations, to delineate sub-surface oceanic frontal regimes and to calculate variations in baroclinic transport. Results indicate that in the open ocean the annual cycle of steric change is determined by temperature changes while over the continental shelf it is mainly influenced by salinity changes. The sixteen-month tide, current and water property survey of the Coastal Ocean Dynamics Experiment (CODE) was terminated in September. These data, covering the west coast of Vancouver Island out to 150 km offshore, are being analyzed to determine the spatial and temporal scales of the coastal circulation and water structure.

Work has begun on a study of meso-scale anticyclonic eddies in the Gulf of Alaska based on 1927-1967 oceanographic data. A particularly well-defined 200-300 km diameter eddy having an average volume transport of $5.5 \times 10^6 \text{ gm m}^3/\text{s}$ relative to 1000 m has been identified off Sitka Alaska. A study of wind-generated inertial currents in Queen Charlotte Sound is presently underway based on data collected during the summer of 1977. An investigation of the propagation and attenuation of internal tides in Johnston Strait, B.C. has been completed. Observations showed the seaward propagating waves to be predominantly of first mode, to attain maximum amplitudes of 20 cm/s near the sill-generation region, to have wavelengths of 20 km and to be damped by bottom friction. Also completed was a multi-volume report on the tides, currents and water properties of the Discovery Passage - Johnstone Strait - Queen Charlotte Strait region for the period 1976-1979.

The Offshore Group was a major participant in the international multi-ship Storm Response Experiment (STREX) conducted in the vicinity of Station P in October and November. As part of a study of the upper ocean response to winter storms, field work included STD surveys, time-series current profiling and the deployment of satellite-tracked drogues.

Analysis and interpretation of the movements of the 300 satellite-tracked buoys launched in the Southern Oceans for the FGGE was begun. In the region of the Antarctic Circumpolar Current surface currents seem to be highly correlated with bottom topography.

(b) Coastal Zone Oceanography

The main experimental effort involved a line of seven stations from the continental shelf break into Alberni Inlet. A regular pattern of CTD stations and five current meter locations has been maintained off the west coast since the spring of 1979 to describe the annual cycle of currents and hydrographic properties on the continental shelf. A region of persistent upwelling has been found which appears to be an important factor governing the local biological productivity, and to be associated

with flows which are generated in local canyons as a secondary circulation response to the spin-up of an intense eddy off the mouth of the Strait of Juan de Fuca. One mooring will be continued near the shelf edge to accumulate statistics on long-term variability.

A related program extends from Barkley Sound into the Alberni fjord system. The shelf water appears to play a major role in the renewal of deep basin water resulting in more or less complete replacement on an annual basis. A decrease in oxygen content was observed, following an initial increase, as dense water continued to flow into the fjord. Above sill depth, strong and frequent exchanges of water between the fjord and the shelf were observed during the late fall and winter months apparently controlled by the offshore wind field. Changes in the shelf density structure produced by the wind stress cause a rapid re-adjustment of the fjord density, above sill depth.

A sonar device built for remotely sensing currents at ranges up to a few hundred metres uses the range gated Doppler technique. Tests confirm the feasibility of the approach while also emphasizing some of the technical difficulties, such as the generation of suitable beam patterns. Development of a more advanced transducer is currently underway.

Analysis of data obtained in Knight Inlet in a joint program with the University of Washington has shown that energy lost from nonlinear internal wave trains generated at the sill is just sufficient to account for the changes in both the density and velocity profiles in the fjord over the 20 km that the waves could be tracked.

Daily salinity and temperature samples have continued at light-house stations along the coast and an additional set of data from Bamfield and Cape Beale have been included in the salinity-temperature reports.

(c) Numerical Modelling

A laterally integrated depth dependent stratified flow model was developed to study simple flushing situations in the Strait of Georgia.

Numerical experiments were conducted to determine if baroclinic three-dimensional flows can be computed more economically by representing the surface as a prescribed flexible "lid" determined from an earlier barotropic model. The full nonlinear effects of the barotropic flow are retained in the baroclinic calculations.

At the request of the World Meteorological Organization, a study of tides and storm surges in the Bay of Bengal was undertaken with the aim of developing a storm surge prediction system for Bangladesh.

A hydrostatic model was developed for study of internal surges in inlets and fjords. A second model using the so-called triple-deck approximation was later used to study the non-hydrostatic regime, including hydraulic jumps, and separation of flow in the boundary layer.

Models were developed to study the propagation of internal Kelvin waves in Knight Inlet, B.C.

(d) Remote Sensing

Development of the airborne spectrometer system for water colour and chlorophyll fluorescence measurements continued with emphasis on the feasibility of making high altitude or satellite-borne chlorophyll surveys using fluorescence line observations. Flights have been repeated at a series of altitudes up to 10,000 ft. using recently acquired

Lowtran-4 software for computing atmospheric corrections. A small amount of Nimbus 7 satellite data on water colour has also been processed. A Loran C unit was acquired and tested and an improved mount for the spectrometer constructed for continuing airborne chlorophyll surveys of the West Coast of Vancouver Island.

Commercial image processing systems are being investigated with a view to acquiring an improved IOS facility in 1981. Application of CODAR and Loran C for surface current measurements were also studied. The Venice Symposium on "Oceanography from Space" was successfully organized in May.

(e) Arctic Oceanography

The polynia project in conjunction with BIO and the boundary layer meteorology group of AES Downsview attempted to parameterise heat loss from open water areas in the ice under winter conditions. Data processing is continuing, but sufficient has been done to show that good and complete data sets were obtained. Loss through ice less than 10 cm thick accounts for about one quarter of all the ocean/atmosphere energy exchange during winter months.

A study of the oceanography of Bridport Inlet on Melville Island, the proposed site of a liquid natural gas tanker terminal was completed and the circulation is presently being modelled. An analysis of the oceanographic survey of the Beauford Sea carried out in November/December 1979 was conducted to support attempts by AES and industry to construct a predictive model of ice movements. The study also investigated the production of dense cold shelf water in the shallows and its movement seaward to mix into the main arctic ocean pycnocline. Continuation of study of oil in sea ice, especially the environmental effects of an underwater blowout in ice covered waters, culminated in an invited address on the topic in St. John's, Newfoundland in December 1980.

Work for UNESCO/IAPSO/ICES/SCOR Working Group 10 on the Practical Salinity Scale 1978 has now received international adoption. Beginning in 1982 it has been recommended that all salinity data be reported in the new scale. Work with IAPSO/SCOR WG 51 on the interpretation of CTD data has led to clarification and design of optimum procedures.

(f) Ocean Chemistry

On-going research continues to concentrate on the marine carbon cycle, hydrocarbons, trace metals and ocean enclosed experiments to understand marine processes and to resolve environmental problems including mine tailings disposal, oil pollution, ocean dumping and environmental contaminant transfer.

A Marine Carbon Research Centre was created as a focus for marine CO₂ activities emphasizing time-series measurements of CO₂ over the ocean at Canadian Weather Station P (50°N, 145°W) now in the eleventh year. Several CO₂ stations were also established at west coast lighthouses as part of the weathership replacement effort along with ship of opportunity collection of air samples across the Pacific on the Canada Maru. An ocean enclosed experiment was conducted in the summer to study the process of heterotrophic transfer of carbon.

A one-year trace metal storage study was conducted for lead, cadmium, copper, cobalt, nickel, zinc and iron in seawater, with a view to developing a NATO reference seawater for trace metals analyses. The ultra clean laboratory continues to demonstrate its usefulness for this work and for ocean dumping studies of release of trace metals from dredge spoils, in particular cadmium. A major Kitimat hydrocarbon baseline

environmental study was conducted by contract. Subsequently, a comparative cause-effect study for Kitimat and Port Alberni areas was made to interpret the relationship between levels of polyaromatic hydrocarbons with disorders in bivalves. A workshop to summarize and disseminate environmental knowledge about the Kitimat marine environment was held in September. Additional joint coastal pollution programs with EPS concentrated on environmental effects of mine tailings involving studies of sediment samples, pore waters, methylation of arsenic and lead and bio-uptake by *M. edulis*. Study of metallothioneins was initiated to understand detoxification mechanisms in marine organisms.

In ocean enclosed experiments, a new experimental system capable of enclosing a seawater/plankton/sediment system was constructed and tested for the SEAFLEXES program. Activities included a Mn/Cu experiment with the Kiel Institut fur Meereskunde, a carbon transfer experiment with the Japanese University of Tsukuba and the Department of Oceanography at the University of British Columbia and an international symposium on Marine Enclosed Experimental Ecosystems sponsored by Woods Hole Oceanographic Institution and hosted at IOS.

(g) Tides and Currents Section

The current survey of the west coast of Vancouver Island, begun in April 1979, was completed in September 1980 with the recovery of eleven current meter moorings and seven pressure recorders. Early results show the tidal currents to be strongly diurnal and the non-tidal currents to be driven by local alongshore winds. Salinity, temperature and current measurements were carried out on the Fraser River delta, as part of a joint program with Coastal Oceanography and the University of Washington to study salt entrainment and to contribute input to the working numerical model of the river.

A study of the behaviour of the surface flow in the Strait of Juan de Fuca was undertaken with small buoys, equipped with transmitters, and dropped into position from an airplane.

The section participated in several special surveys. Results of currents, water property and ocean microstructure measurements made at the equator during the First GARP Global Experiment in 1979 were processed and field work was supervised on board Parizeau during the Storm Response Experiment at Station Papa in 1980.

(h) Ocean Ecology

The major effort of the Ocean Ecology section in 1980 continued to be a biological oceanographic study of the continental shelf region off southern Vancouver Island. High phytoplankton biomass and productivity exist on the shelf region throughout the summer in response to a continual replenishment of subsurface offshore water rich in nutrient and low in oxygen concentrations. This water appears to be injected onto the shelf via tributary to the Juan de Fuca submarine canyon.

Benthic work has consisted of continuing studies on the taxonomy of aquatic oligochaetes, with emphasis on the many marine species being discovered globally, and environmental physiology and ecology, including metal mobilization by worms, and their tolerance to pollutants.

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VIII GLACIER STUDIES

Compiled by: R.M. Koerner

1. Energy, Mines and Resources Canada
Polar Continental Shelf Project
2. Environment Canada
Glaciology Division
3. Karl E. Ricker Ltd., Vancouver, B.C.
4. University of British Columbia
5. University of Minnesota
6. University of Montreal
7. McGill University
8. Memorial University of Newfoundland
9. Bibliography

1. Energy, Mines and Resources Canada

- (a) Polar Continental Shelf Project - R.M. Koerner, D. Fisher, B. Alt
(contract work)

Queen Elizabeth Islands - Down borehole photography and deformation measurements were made in the agassiz (northern Ellesmere) ice cap 1979 borehole. A TV camera and still camera were used for the photograph and vertical strain rates were measured using a laser ranger in combination with a mirror mounted on a caliper. Borehole diameters and temperatures were taken also. Studies to detect increasing acidity levels in the snow over the past 30 years were made at the top of the same ice cap. The mass change along two profiles from the top of the Agassiz ice cap to sea level was measured as was the mass balance of the north side of the Devon Island ice cap. Inclement weather prevented remeasuring Meighen and Melville Island ice cap balances.

Laboratory investigations - The 1977 Agassiz ice cap core studies were continued and a time scale based on seasonal cycles of microparticle, ion and potassium concentrations completed. Volcanic layers as detected by high acid levels in the cores were studies for acid, ion, microparticle, K, Na, Ca, and Al concentrations.

A study of exceptionally warm and cold summers, their effects and causes was completed.

2. Environment Canada

- (a) Glaciology Division - D.K. MacKay, Chief

Glacier Studies - General

Glacier Inventory of Canada - C.S.L. Ommanney, M.M. Strome and J.W. Clarkson, S&ID, NHRI. Work has started on the inventory of the Stikine and Iskut river basins and continues in Glacier National Park. Canadian glaciers contributing to the North Water have been inventoried in a cooperative study with ETH, Switzerland (P. Kraus).

Glacier Studies - Yukon

Glacier Core - Climatic Variations Project, Mt. Logan - G. Holdworth, S&ID, NHRI. A newly constructed "Rufli-Rand" electro-mechanical ice core drill was used at an elevation of 5340 m on Mt. Logan to retrieve 211 m of core. Three holes were drilled: 46, 62 and 103 m in depth. Core from the latter should yield climatic "proxy" data for about the last 500 years. A new borehole notch reamer was used to notch the deep borehole at 5 m intervals (total ice thickness at the

site was measured by radar as 120 ± 5 m). The notches were sensed using a logger fitted with a notch sensing device. A resurvey planned for 1981 will enable the vertical strain rate, and hence the time-depth relationship, to be determined, assuming steady-state conditions.

Ice-dammed lakes - G.J. Young and M. Perchanok, S&ID, NHRI. A reconstruction of the glacial chronology for the Donjek Glacier terminus has been completed. G.K.C. Clarke and M. Perchanok completed assessments of the likely magnitude of floods from this lake.

Glacier Studies - Cordillera

Athabasca Glacier, B.C. - K.C. Arnold, S&ID, NHRI. Aerial survey flights were made at the beginning and end of the melt season to test the feasibility of using aerial photogrammetry to measure ice loss within a single ablation season. A flight with a heat sensing scanner was made over an ice-cored lateral moraine, once in shadow and once in full sunlight.

Columbia Icefield, Alberta and B.C. - K.C. Arnold, S&ID, NHRI and Parks Canada, Western Region. This 1:50,000 map, with rock drawing and shaded relief, is scheduled to be printed on January 26, 1981. The reverse side contains interpretative text and diagrams of glacier and other features of the landscape.

Iskut River Glaciers, B.C. - O. Mokievsky-Zubok, S&ID, NHRI. Studies of three glaciers (106 km) in two watersheds draining into Iskut River representing an ice coverage of 67% and 23% continued to determine their mass balance, their response to climatic changes and their potential influence on the proposed construction of river dams. "Andrei", "Yuri" and "Alexander" glaciers had negative balances of -0.18, -0.73 and -0.52 m H₂O respectively.

Bridge River, B.C. - O. Mokievsky-Zubok and F. Fogarasi, S&ID, NHRI. Studies continued in order to determine the effect of glaciers on basin runoff and to evaluate the seasonal and operational forecast models for a downstream reservoir (with J.R. Gordon, B.C. Hydro). Bridge, "Sykora" and "Zavisha" glaciers had balances of -0.41, -0.41 and -0.81 m H₂O respectively.

Ice-Dammed Lakes - (1) M. Perchanok and the Snow and Ice Division, NHRI. An assessment of the flood hazards from the glacier-dammed lakes in the Stikine/Iskut river basins, B.C. has been completed; (2) O. Mokievsky-Zubok, S&ID, NHRI. Observations continued of glacier dammed Floor and Natavas lakes in the Stikine and Iskut river watersheds. Both lakes were partially filled and discharged in the course of the summer.

Mass Balances, Coast Mountains, B.C. - O. Mokievsky-Zubok, S&ID, NHRI. Measurements of winter and summer balances, meteorological variables and meltwater flow continued on Sentinel and Place glaciers. Mass balance only was determined for Helm Glacier. Specific net balances were -0.78, -0.80 and -1.07 respectively.

Simulation of Alpine Runoff - J.M. Power and G.J. Young, S&ID, NHRI. The monitoring of the hydrology and climatology of glacierized and non-glacierized basins in Yoho National Park continues. Runoff simulation using the UBC forecasting model is being applied to various watersheds in British Columbia.

Peyto Glacier, B.C. - G.J. Young and P.G. Johnston, S&ID, NHRI. Basic monitoring of mass balance, meteorology and hydrology continued.

Atmosphere, Ice and Climate

Albedo measurements on "Andrei Glacier", B.C. - S. Fogarasi, S&ID, NHRI. Spectrally integrated (.3-2.5 m) glacier surface albedos were measured along 2 traverses. Four albedo classes were established in the function of dirt deposited by snowdrift. Influence of rain on albedo variation was assessed and the albedo mapping was attempted.

Comparing Synoptic Estimation of Air Temperatures With Actual Measurements on Mt. Rhonda, B.C. - S. Fogarasi and A.C.D. Terroux, S&ID, NHRI. Air temperature data from an automatic weather station were compared to free atmospheric temperatures estimated from the 700 mbar weather charts. The unbiased estimation and the observed values were close in the region of the mean 700 mbar temperatures.

Sentinel Glacier, B.C. - S. Fogarasi and O. Mokievsky-Zubok, S&ID, NHRI. Daily total direct and diffuse radiation was calculated on a 250 m grid and the sum compared with measured global radiation values. Initial surface albedo was estimated, its daily variation calculated by Petzold's method, and inferences made with respect to the magnitude of attenuation coefficients. Net radiation values were calculated, plotted, and their impact on hydrologic processes examined.

3. Karl E. Ricker Ltd., Vancouver, B.C.

(a) Wedgemount Lake and Glacier, B.C. (with W.A. Tupper)

The scribing of the 1:10,000 scale glacier map of the Wedgemount basin is nearing completion and plans to make it available to the public for 1981 will be worked out with Mountain Equipment Cooperative (Vancouver, B.C.). Nineteen-eighty field work was limited to a visit in late September at the close of the field season to resurvey the lower ice tongue by terrestrial photogrammetry.

(b) Clendenning Creek, Lake and Glaciers, B.C. - Karl E. Ricker and W.A. Tupper, BCIT, and Integrated Resources Photography Ltd., Vancouver. The Clendenning basin lies between the Squamish and Toba River system on the south edge of the large maritime "ice caps" of the Coast Mountains. Extensive analysis of aerial photography reveals that about 67% of all glaciers in the region have shown marked advances since 1964 in most cases and from before 1951 in at least one instance. The studied glaciers will be surface-contoured for all vintages of photography during the 1981-82 winter session by BCIT students, using the now-established aerial triangulation net as the model control.

(c) Glacial Geology of Rocky Mountains - East of Pine Pass area, northeastern B.C. - Karl E. Ricker Ltd. for Gulf Canada Resources Ltd. Quaternary stratigraphy and field mapping at a scale of 1:15840 of all glacial features was undertaken in the following NTS map areas: most of 93-0/8, 93-0/9W 1/2, 93-0/10E 1/2, and a small corner of 93-0/16. Laboratory studies include various soil mechanic properties of glacial till and ice contact gravel samples, as well as provenance studies of their larger clasts. The project is part of a multi-disciplinary baseline study which will be used in the planning of a large coal mining development. The study extends between Mt. Watson and Goodrich Peak on the south, passing northward along the Mt. Lehudette, Mt. Stephenson and Mt. Bickford massifs, and closes off near Beattie Peaks and Mt. Frank Roy on the north. Hasler and LeMoray Creek valleys indicate the width of the study zone. The project marks one of the first attempts to map mountainous terrain on a detailed scale using the ELUC (Environmental Land Use Committee Secretariat of B.C.) modified Fulton method of mapping terrain units.

(d) Permafrost and Ground Ice - Regional Studies of Rocky Mountains - East of Pine Pass area, northeastern B.C. - Karl E. Ricker Ltd. for Gulf Resources Inc. Periglacial features ranging from at least one active rock glacier to various sizes and types of patterned ground phenomena were found on ridge tops above 1850 m during a regional mapping exercise. The approximate extent of their occurrence will be shown on 1:20,000 scale Quaternary geology maps. Preliminary observation suggests that there is a continuum between upslope, patterned ground features of periglacial origin and lobed deposits of soliflucted origin downslope.

4. University of British Columbia

Department of Geophysics and Astronomy - G.K.C. Clarke (with D.E. Thompson and S.G. Collins, Jet Propulsion Laboratory, Cal. Tech.)

(a) Geographical Region: St. Elias Mountains, Yukon Territory - Glacier Surging. The next surge of Trapridge Glacier is approaching rapidly and a large wave-like bulge is building up in the mid-glacier zone. Ice temperatures were measured in seven holes drilled to the glacier bed and it appears that the bulge is forming at the boundary between frozen and unfrozen basal ice.

The flow network established in 1969 was resurveyed and extended. Field studies will continue until the surge is completed.

5. University of Minnesota

Department of Geology and Geophysics - R. LeB. Hooke and Peter J. Hudleston

(a) Barnes Ice Cap, Baffin Island - In May of 1980 a surface movement survey was repeated and it was found again that vertical velocities were lower than Holdsworth measured in 1970-71. In addition, our surface survey was tied into Holdsworth's base line and a roughly 2 m increase in thickness of the glacier since 1970 was found. Hole-parallel strain rates to a depth of 200 m were measured at a place where the ice is about 380 m thick; a roughly uniform strain rate with depth was found.

Analysis of borehole deformation measurements is in progress.

6. University of Montreal

Department of Geography - J.G. Gray and N. Ferron

(a) Chic Choc Mountains, Gaspésie - Approximately 10 rock glaciers have been located so far and ice exposures have been observed in two of them. These rock glaciers appear to have been active post-glacially and some evidence indicates recent movement of small areas at their surface. A drilling program in one of these rock glaciers is planned for the summer of 1981.

7. McGill University, Montreal and ETH, Zurich, Switzerland

Department of Geography - A. Ohmura (for F. Muller)

(a) Queen Elizabeth Islands - Mass balance measurements were made on the Laika Glacier and an ice cap on Coburg Island, on Leffert and an adjoining ice piedmont on Central Ellesmere Island and on the White and Baby Glaciers of Axel Heiberg Island. More deep holes were steam-drilled on White Glacier to continue the study of its thermal structure.

8. Memorial University of Newfoundland

Faculty of Engineering and Applied Science - N.W. Wilson

(a) Ice and Icebergs - As ice melts into saline waters, liquid water with a low salinity is generated at the melt interface. Since this has a lower density than the surrounding sea water, buoyancy forces tend to produce an upward flow. This phenomenon has been studied analytically by a finite difference method. Experimental studies have determined the velocity distributions near a vertical ice wall melting into fresh water.

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IX HYDROLOGY

Compiled by: G.A.D. Greene

1. Introduction
2. National
3. Provincial
 - (a) Newfoundland
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 - (d) New Brunswick
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1. Introduction

This report has been compiled from information gathered through members of the Associate Committee on Hydrology. Since the Committee is composed of membership from the universities, the major provincial and federal water agencies and consultants, this report is representative of hydrological activities in Canada. Hydrological activities in glacier studies and hydrometeorological studies are reported separately under the chapters on Glacier Studies and Meteorology and Atmospheric Science respectively.

2. National

The Canadian Hydrology Symposium:80-Hydrology of Developed Areas was held concurrently with the American Geophysical Union's sessions on Urban Hydrometeorology in Toronto, May 26-27. The Symposium Proceedings are available from NRCC Publications Section. A Workshop on Hydraulic Resistance of River Ice, sponsored by the National Water Research Institute, Canada Centre for Inland Waters and the Working Group on Hydraulics of Ice Covered Rivers, National Research Council was held September 23 and 24 in Burlington.

Agriculture Canada continues to undertake and support hydrologic research in the near surface zones, such as drainage, desalinization and return flows from irrigated lands. Agrometeorology research includes improving water use efficiency, crop yield prediction from soil-water and weather data, and modelling of water use by crops. The soil resource inventory program includes research in soil-water processes, and studies of the impact of shallow groundwater processes on soil properties and uses. An improved approach for characterizing the soil-water regime is under development for use in the soil resource inventory program. Increased activities continue in studies on nutrient runoff from farm land.

The National Hydrology Research Institute (NHRI) continued its research activities in the three broad areas of surface water, ground water and snow and ice. Hydrogeological investigations of the feasibility of disposal of nuclear fuel wastes into mined cavities in the Canadian Shield were again emphasized. Consideration of research needs identified by operational units of the Inland Waters Directorate has led NHRI to plan the expansion of research studies on the influence of ice jamming on flood frequencies and on the effects of agricultural land drainage on runoff. These contacts with operational units also induced NHRI to give priority in the Canadian Glacier Inventory Program to the gathering of information for the Canadian Cordillera in general, with the highest priority being assigned to certain critical sub-areas within the Cordillera. Similarly, NHRI has undertaken to initiate certain short-term studies bearing on practical problems of water exchange between surface water and ground water systems. Hydrologic modelling is being

de-emphasized in order to shift more resources into the investigation of hydrologic processes. Ongoing studies include investigations of evaporation models, the interactions between mining and other northern activities and ground water, runoff from snow melt, glacier mass balance, glacier ice cores and the information they provide on paleoclimates, and the application of r-ray and synthetic aperture radar remote sensing techniques to the estimation of snow cover and snow water equivalent.

The Alberta Watershed Research Program reports a project update on its forest hydrology activities in Marmot and Streeter Basins. In the Marmot Basin the felling to create numerous small clearings on Twin sub-basin has been completed. This is the second and final harvest that was planned for Marmot. The first was to ascertain the effect of commercial operations on the water quality, primarily sediment, and was imposed on Cabin sub-basin in 1974 as a no-subsidy logging operation. This second is a test to verify the understanding of the influence of very small clearings on snow accumulation, snowmelt and subsequent hydrograph alteration. The size of clearings, 1-tree height (1H) in diameter, was the optimum for snowmelt retardation as ascertained from snow studies at the James River snow research site near Sundre. Small 1H clearings are not commercially practical. Therefore this purely research treatment was wholly subsidized. All felling was completed by 15 December 1979. The majority of the merchantable trees were removed during the summer of 1980 under the supervision of the Alberta Forest Service and Canadian Forest Service. The evaluation of this treatment, that is its effect on water yield and regime, will take approximately 5 years. The Canadian Forestry Service and the Water Survey of Canada remain committed to this cause until 1984. The Atmospheric Environment Service will continue to provide instrumentation and servicing to meet "essential needs". In the Streeter Basin the west sub-basin was treated by creating various sizes of clearings to augment snow accumulation, to improve habitat diversity for wildlife and to create better forage and open range area for domestic livestock. The hope was to improve the water yield from local contact springs by retaining snow on their recharge areas which has since been successful. There is visual evidence of increased forage production and both domestic livestock and wildlife use of the clearings. These findings by the Canadian Wildlife Service are being assembled and a joint publication of the range-watershed results is being planned. Preliminary analysis of the spring discharge indicates that the clearing treatment has produced a 48 percent increase in water yield from the West Streeter spring. The Canadian Wildlife Service, Canadian Forestry Service and Water Survey of Canada are committed to continuing evaluation of this treatment through 1983.

3. Provincial

(a) Newfoundland

Newfoundland has begun work with the federal government on a joint five-year study, the Waterford River Basin Urban Hydrology Study Plan. Costs of the study will be shared equally by the two governments. The study will address environmental problems and concerns associated with urban and suburban areas which have reached serious proportions in the Basin. Negative impacts of urban development include changes in river flows; lowering of groundwater levels with consequent drying of wells; flooding and flood damage; deteriorating water quality; loss of recreational facilities and scenic areas; and loss of fish habitats and aquatic life. The study will also address the need for developing standards for water control structures such as storm sewers, urban drainage systems, bridges and culverts. The results of the study will help the provincial Environment Department in the development of planning and management criteria for all aspects of urban development relating to the environmental protection of water resources. Guidelines for environmental protection measures will also result from the study. The study is part of the provincial Environment Department's water resource

management and environmental impact assessment program designed to provide quantitative evaluation of all land uses and to develop environmental control guidelines.

(b) Prince Edward Island

The Water Resources Branch of the P.E.I. Department of Community Affairs conducted a field study for a groundwater project on the permeability and porosity in a fractured - porous aquifer for the Winter River Basin. P.E.I. depends entirely on groundwater resources for its municipal, industrial, and rural water supplies. The Permo-Pennsylvanian bedrock of the Island is essentially the only exploited source of water. Responsible groundwater resource management requires understanding and quantification of the basic parameters controlling groundwater supply and contaminant transport. Permeability and porosity of an aquifer are determining factors in the occurrence and movement of groundwater. In the past, determination of aquifer properties has consisted principally of applying methods of analysis whose theoretical assumptions are not met by field conditions. Therefore, extrapolation of results obtained is not reliable. A common question, such as the effect of long term interference of municipal wells on private wells, could not be answered with a high degree of certainty.

(c) Nova Scotia

Nova Scotia Technical College continued studies of urban storm water quality and quantity with the adaptation of appropriate models.

(d) New Brunswick

The Nashwaak Experimental Watershed Project was initiated in 1970 on three small forested watersheds in Central New Brunswick. One watershed was established to serve as control, one watershed was set up to study the effect of clearcutting on the hydrological regime, and one watershed was established to study the effect of fertilization on the nutrient balance. The aerial fertilization experiment was carried out in 1975. The calibration for the watershed to be clearcut extended from 1971-78. This watershed was clearcut in 1978-79. Results related to the post treatment response of both watersheds are now available.

Detailed field measurement of channel geometry have been made on a reach of the Nashwaak River near Fredericton. Observations of the winter ice regime and measurements have been made to determine resistance to flow under ice cover. These results are compared with those predicted by various empirical equations.

A pilot project has been established in the Shippegan - Caraquet area of Northeastern New Brunswick to develop a groundwater management strategy. This is an area in which groundwater is a major water resource and it is also one in which salt water intrusion can be important.

The Flood Forecasting Centre in Fredericton has an ongoing project to evaluate the hydrometeorological network in the Saint John River Basin as it affects the accuracy of the forecasts made by the Centre.

A project on remote sensing of off-channel storage volumes in the Lower Saint John River has been established with the purpose of using remote sensing techniques to determine the amount of off-channel storage associated with the lower Saint John River. This project is being carried out in cooperation with the Canada Centre for Remote Sensing.

(e) The Quebec Government in a major reordering of its Cabinet structure has created two new ministries reflective of the growing importance of

resource management and environmental control at the provincial level. In late 1979, the province created a new Ministry of the Environment. Also, the Ministry of Energy and Natural Resources has replaced the old Ministries of Lands and Forests and Natural Resources. The new Ministry of the Environment is responsible for the conservation, protection and management of the environment. The Ministry is also responsible for the administration of ecological reserves, the expansion of Hydro-Québec, the development and utilization of the mineral and energy resources of Quebec, and the implementation of long-term programs to prevent or lessen the damage caused by flooding, soil erosion and landslides. The new Ministry of Energy and Natural Resources has very broad responsibilities, including the management and granting of rights of ownership and rights of use of forest, hydraulic, mineral and energy resources, as well as the devising and carrying-out of plans and programs for the enhancement and development of these resources; the development, conservation, improvement and protection of forest lands; and the setting-up of laboratories for research in mineralogy, metallurgy, hydraulics, forestry and energy.

Ecole Polytechnique continued its research in urban hydrology, concentrating mainly within the Montreal region. Precipitation studies included the stochastic modelling of precipitation; mathematical methodology; spatial variations of storms; and the influence of an urban zone on precipitation. Flood studies included the analysis by a stochastic model; methodology to estimate direct damages in floodplains, floodplain management; sampling effects on the characteristics of a stochastic model for flood analysis; benefit-cost analysis for different methods of flood control; and regional analysis for estimating flood peaks in small watersheds. Quality aspects included the statistical analysis of quality parameters for surface water; development of a quality index for uses of water; spatial and temporal distribution; data collection within the Montreal Urban Community sewer system. Rainfall-Runoff Modelling included a sensibility analysis for the Illudas model; the comparative study of the SWMM and Illudas models; the application of Box-Jenkins techniques to different parameters of the rainfall-runoff phenomenon; and the development of a runoff model to anticipate runoff discharge. Control Modelling included a preliminary study of real-time operation of a sewer system; improvement of simulation of flow with an interceptor; and a dynamic programming technique for optimization.

(f) Ontario

A Great Lakes Institute has been established at the University of Windsor. Its objective is to be an educational and research centre of excellence concerned with environmental issues of man and the biosphere. An interdisciplinary approach to these issues will be achieved by utilizing the expertise in the various departments within the University. As its focal point, the Institute will develop and apply pure and applied research capabilities to major environmental issues in the Great Lakes Basin. The Institute will also provide non-credit seminars, workshops and symposia on scientific, engineering, social and economic activities within the Great Lakes and surrounding area as they relate to the integrity of the Great Lakes ecosystem. The Institute has more than thirty physical and social scientists with expertise in many related fields such as: biology, chemistry, civil engineering, geography, geology, social sciences and law. Well-equipped laboratories are available for research in each of the areas named. Specialized equipment includes: scanning and transmission electron microscopes, climatic and water quality monitoring equipment, Coulter counters, GCS mass spectrometer, scintillation counters and atomic absorption spectrophotometers. An IBM 3031 computer is on hand for data storage and analysis. In addition, the University of Windsor maintains a research station on Lake Erie.

Queen's University research is concentrating on studies of frequency analysis, real-time flood forecasting and basin modelling.

(g) Manitoba

Existing forecasting procedures for the Red River Basin south of the City of Winnipeg were revised by the Water Resources Branch so that probabilities could be assigned to the spring runoff forecasts. Previously, forecasts were issued for median and upper decile future precipitation, but no allowance was made for variations in the other variables which affect spring runoff. Therefore, a study of the joint probabilities of various combinations of variables including precipitation, melt rate, and flow rate estimates was conducted so that accurate probabilities could be assigned to spring runoff forecasts. Research continued in the Wilson Creek Experimental Watershed with the collection of new hydrologic data, analysis of previously collected data, and the construction for experimental purposes of a series of energy dissipating rock-filled weirs. The Water Resources Branch has recently begun studying the feasibility of enhancing both the quantity and quality of groundwater by injecting high quality surface runoff water into both surficial sand and gravel aquifers and confined bedrock aquifers. Investigations are being planned for aquifers within the Red River Valley southwest of Winnipeg. The Branch has also begun an evaluation of the feasibility of utilizing relief wells to reduce the pressure in confined aquifers where agricultural drainage systems are adversely affected by excessive discharge of groundwater in the form of springs and "blow outs" in the bottom of drainage channels.

(h) Saskatchewan

A discussion paper on Agricultural Drainage Impacts in Saskatchewan has been prepared by the Investigations Division of the Hydrology Branch, Saskatchewan Environment. The paper presents a method of study of the downstream impacts of drainage of agricultural lands. This method has evolved through a process of study of several watersheds in Saskatchewan.

(i) Alberta

A major study, commissioned by the Alberta Department of the Environment, provided estimates of probable maximum precipitation for the major river basins in Alberta. The physical analysis was based on some 600 storms over the period of record. For the sake of comparison, a statistical technique was employed to estimate probable maximum precipitation at all first order stations. In order to determine the effect of systematic land drainage activities on hydrological characteristics a field study of runoff from drained and undrained agricultural land in the same vicinity was begun this year. This first year results show a marked difference. The rate and total amount of snow melt is an important ingredient in forecasting stream flow in Alberta. Continuing studies relating the information gained from snow pillow data to climatological factors are proceeding. The ability of the Alberta River Forecast Centre to forecast runoff from snow melt is steadily improving. Recent flood control activities of the Alberta Department of the Environment in a number of river floodplains throughout the Province has prompted a renewed necessity for both research and engineering design related to the effects of cutoffs, channelization and dyking on stream regime. Erosion, sediment transport and the efficiency of cutoffs have all been subject to an intensive program of observation and analyses.

(j) British Columbia

At the University of British Columbia, the Department of Civil Engineering has developed a computer program for using both data and

judgement to estimate flood frequencies. Work continues on the application of information theory concepts to hydrologic network design, on the impact of sedimentation on floods, on the development of a self-contained electronic water level recorder, and on the estimation of precipitation from GOES satellite images.

In the Faculty of Forestry, the effects of herbicide application on nutrient movement into streams is being studied at the UBC Research Forest. Two streams are monitored above and below a treated plantation. The effects of clearcutting and slashburning on watershed nutrient budgets and on nutrients in streams are being studied on four gauged watersheds scheduled for clearcutting in 1982. Study continues on the effects of logging in the Jamieson Creek Experimental Watershed (Greater Vancouver Water District). Logging began in 1980 and will continue for 5-8 years. A study of water repellency in soils of the watershed with various land use histories was conducted this summer.

In UBC Geography Department the former vegetation of Fraser River floodplain is being studied. The role of evapotranspiration in the water balance of the city is being examined by measurements of short-term response of city surfaces to wetting by precipitation/irrigation, and the seasonal pattern of rural/urban evapotranspiration differences. The Miller Creek experimental basin continues operation with emphasis on streamflow generation, variable solute sources, and surface wash. Field investigations are carried on of solute rejection beneath aggrading permafrost and of freezing point depression of subpermafrost porewater. Fluctuations of hydrological components in British Columbia within the past 300 years are being studied. A snowmelt seepage model has been developed.

Research in the Department of Geological Sciences is directed in three areas: Hydrogeology of the Meager Mountain geothermal reservoir; applications of groundwater flow theory in understanding the genesis of stratabound Pb-Zn ore deposits; seepage from heterogeneous slopes, with emphasis on geomorphological applications.

In UBC Soil Science work is underway on developing evapotranspiration models for crops and forests as part of crop and forest water balance models for the growing season. The effect of tillage on the rate of evaporation from bare soil has been studied and is being modelled. It has been found that a significant portion of precipitation reaches the soil surface of a West Coast mountain slope soil via point sources, with vegetation and slash, which covers up to 30% of the soil surface, acting as concentration elements. The flow of water in the soil below a point source is gravity driven. This mechanism explains the flashy response of West Coast streams to rainfall events.

The Department of Geography at Simon Fraser University is maintaining its program of monitoring flood hydrograph characteristics in several small urbanising drainage basins in the Municipality of Surrey. Funding has been received for the construction of an experimental watershed on the Simon Fraser University campus which will be operational by summer 1981 and will be used to model hydrologic responses to environmental changes in small drainage basins.

X MINING GEOPHYSICS

Compiled by: Norman R. Paterson

A. Industry

1. McPhar Geophysics, Toronto
2. EG & G Exploranium/Geometrics, Toronto
3. Edwin Gaucher, Instrumentation GDD,
Sainte-Foy, Quebec
4. Scintrex Limited, Toronto
5. Geoterrex Limited, Ottawa
6. Sonotek Limited, Toronto
7. Barringer Research Limited, Toronto
8. Questor Surveys, Toronto
9. Urtec Limited, Toronto
10. Phoenix Geophysics Limited, Toronto
11. EDA Instruments Inc., Toronto
12. Hunttec ('70) Limited, Toronto

B. Government

1. Geology/Geochemistry Section,
Ontario Geological Survey,
Ministry of Natural Resources, Toronto
2. Resource Geophysics & Geochemistry Division,
Geological Survey of Canada
3. Geology and Mines Division,
Saskatchewan Mineral Resources,
Saskatchewan

C. Universities

1. Geophysics Laboratory,
Department of Physics,
University of Toronto
2. Department of Geophysics,
University of Western Ontario
3. Department of Geology & Geophysics,
University of Calgary
4. IREM-MERI/Ecole Polytechnique, Montreal
5. Department of Geology,
University of Toronto

Compiler's Comments:

Only 19 organizations reported activity in mineral exploration geophysics research in 1980. It is the compiler's opinion that this does not reflect a drop in activity but, rather, the opposite. The individuals responsible were too busy carrying out research-related functions to spare the time to answer tedious requests for information.

In fact, as may be noted in the excellent review by P.J. Hood in the Canadian Mining Journal, February 1981, research activity, at least in the private sector, is probably at an all-time high. Readers are referred to Hood's article for a comprehensive review of commercial developments in mining geophysics in 1980.

As was the case in 1979, the level of research in many organizations in Canada has been limited by the availability of qualified staff rather than by available funding. Several universities have reported that research grants had to be refused because of a shortage of academic staff or students. In industry, petroleum companies continue to hire most geophysics graduates and

there is a severe shortage of qualified personnel in the mining geophysics industry. This is particularly so in the service and manufacturing sectors where the bulk of mining geophysics research is traditionally carried out.

A. Industry

1. McPhar Geophysics, Toronto

The company reported continued activity under J.G. Conaway in the development of application of portable, computerized logging systems and slim-hole multi-parameter probes. The RD-600 computerized logging system with built-in microcomputer provides on-line processed data at the drill site. The same system carries out off-line data enhancement for specialized interpretation purposes.

A microprocessor-based ground proton magnetometer, model GP-80, is being developed for both portable and base station use. Features include built-in printer with accurate time reference and "status message".

McPhar is introducing a number of mobile computer systems for verification, analysis and duplication of airborne survey data. Special purpose software programs perform a number of useful functions that render the data field-useable and reduce the turnaround time in the office.

2. EG & G Exploranium/Geometrics

Research was carried out in the areas of seismics, magnetics and radiometrics. A new 24-channel high resolution seismograph was developed for both refraction and reflection operations, and a companion nine-track unit is planned for digital recording in the field.

A cartridge based acquisition system was developed for profile or base station magnetometer operations. Interfaces are being developed for borehole applications that will allow an automatic recording of gamma ray and winch depth data.

A new airborne proton magnetometer has been developed with a resolution of up to 0.01 gamma (at 3 sec repetition rate). The unit is being used by the U.S. Geological Survey to measure orthogonal horizontal gradients, permitting the computation of the vertical magnetic gradient.

3. Edwin Gaucher/Instrumentation GDD, Sainte-Foy, Quebec

Improvements were introduced in the portable conductive float detectors (Beep Cane and Beep Boot). Mineralized boulders have been detected to a depth of greater than 1 meter.

Some IP experimentation was done with very short dipole spacings principally to locate gold-bearing sulphide veins.

4. Scintrex Limited, Toronto

The company improved its helicopter geophysical systems by the introduction of the two-frequency HEM-802 EM system which has a noise level below 1 ppm with a 9m coil separation.

A video flight path recorder system was also introduced in 1980, offering advantages in field processing, cost, etc.

Drill IP logging was carried out with the new IPR-11 broad-band time domain receiver. This unit's solid state memory facilitates the automatic field plotting of the drill-hole IP section on a digital printer.

The company continued development of field portable geochemical analytical instrumentation, including a novel atomic absorption spectro-photometer. Under active development is the AAZ-2 Zeeman Modulated Atomic Absorption Analyser which will allow a determination of trace Pb, Zn, Cu, Ni and Ag in the field. Concentrations as low as 1 ppb may be detectable in some cases.

Development continued in spectrometer systems, including advances in on-line processing of data by microcomputer. A portable drill-hole logging system was also developed, with a novel recording console which accepts modules for a variety of logging sensors.

5. Geoterrex Limited, Ottawa

Work was continued at the University of California, Berkeley, in the development of a helicopter-borne superconducting single coil EM system.

Further development also took place in conjunction with Barringer Research and Aquitaine on the COTRAN airborne EM system. Fairly extensive field trials were conducted during 1980.

A ground geophysical test site is being prepared at Calabogie, near Ottawa, to be available to the geophysical fraternity for the testing of instruments and methods.

6. Sonotek Limited, Toronto

R & D efforts at Sonotek were primarily directed at the preparation of new software for the company's microprocessor-controlled logging systems. This is intended to enhance their capabilities for data processing in the field. Data processing functions include calculations of hole position, uranium grade calculations, digital filtering, spectrometric corrections and graphics.

Various hardware developments were also undertaken in the year.

7. Barringer Research Limited, Toronto

The company reported the continued development of the COTRAN airborne EM system. The first test survey was flown for the Geological Survey of Canada in the Athabasca Basin, the results of which will shortly be placed on file by the GSC. A second test program of 1,000 line kms was carried out over known massive sulphides in Wisconsin and Minnesota.

Barringer Research and PetroCanada Exploration are to jointly develop the TIVAC system for airborne oil and gas exploration. The system detects hydrocarbon leakage by remote sensing methods. The development is also supported financially by the National Research Council of Canada.

During 1980 development was completed of the Ratioing Radiometer, an instrument which measures the energy reflected on the ground as pairs of visible or infra-red wavelengths. It is designed to identify and classify various types of clay minerals and is particularly suited for use in conjunction with satellite imagery.

8. Questor Surveys Limited, Toronto

The company commenced the development of a helicopter version of the INPUT airborne EM system and successfully test-flew a prototype transmitter in a Bell 212 helicopter.

A program of fundamental research on airborne EM survey principles was initiated with the objective of optimizing INPUT data acquisition.

Research was undertaken in high-sensitivity helium vapour magnetometer measurements and the application of these sensors to airborne magnetic gradiometry.

9. Urtec Limited, Toronto

The company reported developments in airborne data acquisition methods and both magnetic and radiometric instrumentation.

The UDAS (universal data acquisition system) is now available in various configurations, with recording capacity up to 16 channels and data control for full spectra gamma-ray analysis. The system can also be used as a field data verification and processing unit with on-line graphics capability.

During 1980 Urtec carried out a flight evaluation program in conjunction with Varian Canada Limited to test the feasibility of using optically pumped caesium cells for use in low sensitivity magnetometers.

Various portable magnetometer and gamma ray spectrometer units and interface systems were introduced during the year.

10. Phoenix Geophysics Limited, Toronto

Active research areas were spectral IP, AFMAG/AMT and MT.

In spectral IP, research was carried out in the study of chemical reactions on mineral surfaces, the IP effects of mineral texture and geometry, the removal of inductive coupling effects, the use of spectral IP in hydrocarbon exploration and the testing of spectral IP for mineral discrimination.

Development was undertaken on a portable tensor AMT unit and remote reference MT hardware and software.

11. EDA Instruments Inc., Toronto

The company developed and introduced a series of stationary and portable microprocessor-based proton precession magnetometers using a novel noise suppression technique which achieves high sensitivities with short, low-power polarization. The PPM-105 total field magnetometer, with a sensitivity of 0.01 gamma, is in operation in 16 USGS observatories. The unit is now being used in a portable vertical gradiometer mode in the PPM-500 gradiometer.

12. Huntec ('70) Limited, Toronto

Most of the R & D effort in 1980 went into the improvement of the company's 2.5 kW and 7.5 kW IP transmitters. These units will now function in both the time and frequency domains and both have automatic current regulation.

B Government

1. Geology/Geochemistry Section, Ontario Geological Survey, Ministry of Natural Resources, Toronto

The Section completed airborne EM surveys totalling 27,000 line km in several areas of Ontario, using four different airborne systems: Questor Mk VI INPUT, Scintrex HEM-802, Aerodat HEM and Scintrex/Kenting TRIDEM. Reports were issued, together with interpretation manuals prepared under a research program in airborne EM computer modelling (based on the University of Toronto plate in free space computer program).

Interpretation was carried out of the results of a 4-year gravity survey program of the Cobalt Embayment - Grenville Front areas.

In conjunction with the Department of Earth Sciences, University of Manitoba, crustal seismic studies were performed along a profile from Vermillion Bay to north of Red Lake.

2. Resource Geophysics & Geochemistry Division, Geological Survey of Canada

Test surveys were carried out with a variety of EM instruments, primarily to assess their application to deep sounding and geologic mapping. For deep studies the MAXI-PROBE multi-frequency and Geonics EM-37 wide-band transient EM systems were tested at Chalk River, Ontario and at Pinawa, Manitoba. For mapping and for detecting fracture zones tests were conducted with the MAXIM II, the Geonics EM-34 and the VLF EM method. Both local and naval VLF stations were used. The drill-hole VLF EM system developed by MERI, Montreal, is being applied to spectral mapping problems in the AECL waste management program.

Shallow refraction and reflection seismic surveys were conducted primarily to determine the thickness of Pleistocene surficial deposits. Successful reflection studies were performed by mating the Geometrics ES-1210F seismograph and G-7245 digital recorder with an Apple II micro-computer. Using appropriate software, reflection profiles were obtained of the bedrock interface at depths as shallow as 30 meters.

Similar seismic experiments were conducted in the Dismal Lakes and Baker Lakes areas of the NWT to test the method for mapping layered stratigraphic facies at a depth of several hundred meters.

Borehole seismic studies were made in connection with the AECL waste management program at Chalk River and Pinawa. The records obtained displayed many large amplitude-low velocity events which were identified as tube waves originating at fluid-filled zones intersecting the boreholes. This promises to be an important geophysical technique for detecting permeable zones directly.

The aeromagnetic survey of Canada continued at a reduced rate, with the publication of 491 new aeromagnetic maps. High resolution aeromagnetic gradiometer surveys were flown in some areas, including the underground research laboratory site at Pinawa, Manitoba.

Airborne gamma-ray spectrometer surveys were flown in six different areas and the results will be published in 1981. Ground investigations and interpretation of airborne survey results continued at Sharbot Lake, Ontario, and in several parts of New Brunswick.

All of the airborne spectrometer data collected by the GSC SkyVans since 1969 are being compiled into a new data base in preparation for producing and publishing 1:100,000 and 1:5,000,000 scale colour maps of radioelement distribution.

Field trials were carried out of the McPhar prototype RD-500 borehole logging system and the INAX 540 portable XRF analyser.

The borehole calibration facilities at Bell's Corners, Ottawa, were expanded by the addition of six density model holes.

3. Geology and Mines Division, Saskatchewan Mineral Resources

Reports are in preparation on several field investigations and airborne surveys. Specifically, these include an assessment of uranium potential of lake-covered areas; an integrated geophysical compilation and interpretation of the Athabasca Basin; and a report on seismic investigations in the Athabasca Basin.

C. Universities

1. Geophysics Laboratory, Department of Physics, University of Toronto

B. Dickson and R.C. Bailey applied inverse theory and factor analysis to the problem of interpreting airborne gamma-ray spectrometer data. Factor analysis of spectra from the calibration pads at Grand Junction, Colorado suggests that it should be possible to simultaneously and optimally obtain both ground radioelement concentrations and overburden thickness.

Support for this project is being provided by Energy, Mines and Resources and NSERC.

EM prospecting studies continued under Ontario Geoscience Research and NSERC funding. Under the general supervision of G.F. West, advances were made by J. Macnae, A. Dyck, T. Eadie, C. Villegas and others.

Macnae continued research on the application of the UTEM transient EM method to structural mapping. A. Dyck continued his work on EM computer modelling and the analysis of drill-hole EM data. T. Eadie produced a set of interpretation nomograms for determining the electrical parameters of overburden with standard horizontal EM methods. C. Villegas made a comprehensive study of how the horizontal loop EM method responds to step-like, ridge-like and valley-like features in conductive overburden.

A major facility for analogue scale model studies was completed and put into operation for modelling frequency domain EM systems. A new wide-band electronic system for modelling time-domain EM systems has been designed and installed.

R.N. Edwards and E. Gomez-Trevino studied the geology of the Paleozoic sedimentary basin of southern Ontario by means of a wide-band (0.03 Hz to 15 kHz) EM system. Support was obtained from Imperial Oil and NSERC.

R.N. Edwards and H. Urbanski applied geomagnetic depth sounding to the investigation of the very deep structure of base metal mineral deposits. New traverses were run over the Sudbury Basin and analysed by both MT methods and in the form of transfer functions between magnetic components. The project is supported by Energy, Mines and Resources.

AMT studies were carried out under the AECL waste management program by D. Hsu, J.D. Redman and D.W. Strangway. Surveys were completed at Chalk River and Pinawa. Studies were also carried out, in co-operation with Woodward-Clyde Inc., in the SW United States, for the U.S. Department of Energy. Funding has been obtained for these studies from Energy, Mines and Resources, NSERC, AECL, Woodward-Clyde and DOE.

J.D. Redman and D.W. Strangway, under an Energy, Mines and Resources research agreement, continued to develop a digital acquisition system for tensor AMT sounding. Co-operation is being provided by Scintrex Limited.

J. Wong and D.W. Strangway conducted research on the relationship between electrical properties and water content. NSERC and Energy, Mines and Resources funding was provided.

J. Wong, P. Hurley and G.F. West studies the development of a source-detector transducer system for borehole-to-borehole seismic measurements, for application primarily in the AECL waste management program.

G.F. West continued studies into the geotectonic processes that may have affected the formation of the Archean crust, based on analytical and numerical modelling of various thermal and flow processes.

F.G. West and M. Bloore continued to improve the EM computer modelling software library at the Geophysics Laboratory, by enlarging its scope and increasing its accessibility to outside users.

2. Department of Geophysics, University of Western Ontario

C.J. Mwenifumbo and L. Mansinha studied the mise-a-la-masse responses over 3-D tabular conductors by means of scale model experiments.

K.V. Allen and A. Hayatsu studied quantitative interpretation of gamma-ray spectral logs using computer models of mixed uranium-thorium ore zones.

G.H. Schmit and A. Hayatsu investigated the effects of borehole diameter, pore content and casing on the system response functions and sensitivity in gamma-ray logging in small diameter boreholes.

A.S. Thompson and H.C. Palmer carried out studies of interpretation methods for total magnetic field vertical gradient surveys.

3. Department of Geology & Geophysics, University of Calgary

With the support of a Calgary-based mining company development work continued on an airborne gamma-ray detection system with certain performance advantages over other commercially available devices.

A project is underway to study the electrical behaviour of Pb-Zn ores in permafrost environments. Test surveys have been conducted and a large suite of specimens has been obtained. Laboratory analysis is being undertaken with the aid of a Hunttec MK.4 receiver and data processor. Industrial and NSERC funding is acknowledged.

Construction of an analogue scale model facility for EM and galvanic prospecting is in progress with financial support from the Province of Alberta and two Calgary-based mining companies.

4. IREM-MERI/Ecole Polytechnique

Progress is reported on research in EM, AMT, MT, AFMAG and IP.

A field portable MT/AFMAG profiler-receiver is being developed around a hybrid computer. The receiver will measure the amplitude ratio, the phase shift, and the coherence between two EM field components in the frequency range 2 Hz to 20,000 Hz.

Work is in progress on direct Cole-Cole interpretation methods from time-domain IP data.

Development work is continuing on a compact, field-portable, micro-computer controlled drill-hole logger for EM and IP methods.

5. Department of Geology, University of Toronto

J. Bambrick, S. Letros and D.W. Strangway continued studies in the interpretation of high-resolution aeromagnetic data in the Abitibi greenstone belt. This project, supported by the Ontario Geoscience Research Fund, has been in progress since 1978. It has involved the testing and improvement of various data enhancement techniques for resolving the magnetic structure of the ground.

J. Bambrick, S. Letros and D.W. Strangway were appointed principle investigators in the MAGSAT program (a magnetic recording satellite launched

into high inclination orbit in October 1979). NSERC financial support has been obtained.

F.W. Beales, D. Bending and K.C. Claesson studied the paleomagnetic characteristics of Mississippi-valley ores for age dating purposes. This project has Energy, Mines and Resources and NSERC funding.

Paleomagnetic studies are being carried out by R. Ernst and H.C. Halls by sampling diabase dykes in the Kapuskasing structural zone. The studies are aimed at investigating the possibility of large-scale rotations and uplift which appear to be associated with the zone. NSERC funding is acknowledged.

J. Geissman, A. Tasillo and D.W. Strangway continued studies of the magnetic bodies of the lake river volcanics, under an Ontario Geoscience Research Fund Board. Magnetic properties of rock samples, supplemented by aeromagnetic data, are being used to recover the paleomagnetic directions of early archean times.

Other paleomagnetic studies continued under H.C. Hall, D.W. Strangway and others in connection with various geological research programs.

XI PETROLEUM GEOPHYSICS

Compiled by: A. Easton Wren

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2. Field Acquisition
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1. Introduction

The level of geophysical activity in 1980 reached a new record high in the early part of the year, tapered in the summer and, for the first time in several years, has not staged the traditional year end revival. While the number of active crews is expected to reach 100 in the early months of 1981 this will be largely due to commitments made prior to the recently introduced Federal Budget and Energy Programme. The latter have resulted in substantial cut-backs in exploration expenditures, and service companies, particularly seismic crews and big-rigs, are experiencing a severe shortage of work.

1980 was another year of consolidation of techniques rather than one of substantial technological breakthrough. Relatively new techniques such as 3-D, shear waves and V.S.P. were firmly established. Interactive modeling maintained its position as the key interpretive tool, linking geologists and geophysicists in terms of solving exploration problems.

2. Field Acquisition

Multichannel recording systems, with special emphasis on 3-D, continue to increase in application. The industry is rapidly finding ways to make full use of the high density recording capability with fully preserved integrity. In practice these systems are approximating much more accurately a point-source, point-detector system. We have better resolution in time and space.

Recent advances in fiber optic technology have attracted attention as a medium for seismic telemetry. Fiber optic data transmission has many attractive features including very high data transmission rates, distortion and noise reduction, electro magnetic interference immunity and substantial expansion in bandwidth. Current trends in fiber optics communications applications are most encouraging.

A traditional limitation of the *Vibroseis system has been its restricted input bandwidth. This is particularly restrictive with respect to high resolution acquisition. The system depends on the ability of vibrators to generate synchronous, repeatable sweeps over the frequency range of interest. Conoco has developed a new high frequency vibrator (200 Hz) and has demonstrated successful application of vibroseis high frequency data in stratigraphic exploration problems.

3. Shear Waves

The use of S-wave generation and recording in conjunction with the traditional P-wave is rapidly becoming more acceptable to the industry. There is no question that the technique is now past the experimental stage. A basic requirement for absolute calibration is a Vertical Seismic Profile (V.S.P.).

* Trade Mark - Conoco

4. Seismic Data Processing

The most important recent developments in processing, wave equation-based imaging and inversion methods, may be the fore-runners of a totally new processing methodology. Wave equation methods have been formulated for migration before and after stack, multiple suppression, datum and replacement statics, velocity analysis and inversion. Inversion now has widespread application. Wavelet processing has expanded the capability for stratigraphic analysis.

5. Modeling

Interactive graphics modeling techniques continue to expand and open new horizons for interpreters intent on converging on optimal solutions to data sets. It is a simple matter to input sonic and density logs, digitize and edit and generate synthetic seismic traces by varying geological parameters. Geological interfaces are precisely defined and there is ultimately a better match of synthetic to actual seismic data.

1-, 2- and 3-D modeling techniques are commercially available.

6. 3-D

3-D acquisition and processing systems have been available for several years but interpretation techniques have lagged behind. There is a basic need for improved methods to handle and interpret the mass of data being accumulated. This is being facilitated to some extent by 3-D interactive graphics modeling.

3-D acquisition relies heavily on current 1024 - channel systems.

7. Gravity

New developments in interactive graphics hardware and software are revolutionizing both processing and interpretation. Higher quality shipborne gravity data, improved borehole gravity data processing and better integration of gravity and seismic are on the increase.

8. Magnetics

There have been enormous amounts of magnetic data collected over the last 20 years or more. More and more detailed surveys have been undertaken with more and more sophisticated instruments. Current practices fall into three areas -

- (a) Digital processing to facilitate handling and interpretation.
- (b) Compilation of regional anomaly maps.
- (c) Progress in interactive modeling similar to gravity and seismic.

9. University of British Columbia

R.M. Clowes (Geophysics and Astronomy, University of British Columbia) and E.E. Davis (Pacific Geoscience Centre, EMR) are investigating the diagenesis of sediments in Winona Basin, a young deep water basin along the base of the continental slope off central British Columbia. The basin has filled with turbidite sediments during the Pleistocene. Continuous seismic reflection profiles, multichannel reflection data from the petroleum industry, wide-angle reflection and seismic refraction data are combined with analyses of dredge samples. In some locations, the sediment thickness is more than 4.0 sec. two-way traveltime. A rapid process of lithification caused by calcium carbonate cementation is inferred.

