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Ottawa, Canada

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INTRODUCTION

The current volume of the Canadian Geophysical Bulletin is the twenty-ninth in a series aimed at providing a review of geophysical activity in Canada. Originally the responsibility of the Associate Committee on Geodesy and Geophysics of the National Research Council from 1948 to 1973, the Bulletin has, since 1974, been published under the authority of the Canadian National Committee for the International Union of Geodesy and Geophysics.

The chapters in volume 29 follow the sequence used in previous Bulletins. In general the disciplines reported upon correspond to the Associations of the IUGG, with some important additions - Glacier Research, Isotope Studies and Geochronology, and Exploration Geophysics. The latter are included because of their special relations, in Canada, with the more "traditional" disciplines of the IUGG. Once again a brief report on Mathematical Geophysics has been included to draw attention to the active associations which have developed, across the traditional discipline boundaries, within the Canadian Geophysical Union. The annual report on Geodynamics has not been prepared this year. Although the International Geodynamics Project is continuing, the studies of which it is composed are all adequately described in other Chapters in the Bulletin. A chapter on Volcanology has again been included, but no report on Oceanography is available.

The editor wishes to acknowledge with thanks the assistance of members of the Canadian Geophysical Union, the Division of Aeronomy and Space Physics of the Canadian Association of Physicists, the Canadian Meteorological Society, the Canadian Institute of Surveying and the Associate Committee on Hydrology, in supplying and compiling the chapters and bibliographies. The Bulletin has been produced and distributed by the Earth Physics Branch of the Department of Energy, Mines and Resources at the request of the Canadian National Committee for the International Union of Geodesy and Geophysics and the Canadian Geoscience Council.

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

The assistance and hard work of Ms. M. Bradfield, Ms. J. Legere and Mr. E.B. Manchee in preparing the material for publication is very gratefully acknowledged.

R.M. Farquhar
Editor

INTRODUCTION

Le dernier volume du Bulletin canadien de géophysique est le vingt-neuvième de la série qui a pour but de donner un aperçu des activités géophysiques au Canada. Le Comité conjoint de géodésie et géophysique du Conseil national de recherches, a été le premier organisme responsable de ce bulletin, de 1948 à 1973; depuis 1974, il est publié sous la direction du Comité national du Canada de l'Union Géodésique et Géophysique Internationale.

Les chapitres du volume n° 29 sont classés dans le même ordre que les volumes précédents. En général, les disciplines dont il est question sont celles qui intéressent les associations de l'UGGI, avec quelques additions importantes, comme la recherche en glaciologie, les études d'isotopes et la géochronologie, et l'exploration géophysique. Ces dernières sont incluses vu leurs liens particuliers, au Canada, avec les disciplines plus "traditionnelles" de l'UGGI. Une fois de plus, on a joint un bref rapport sur les mathématiques de la géophysique, afin d'attirer l'attention sur les associations actives qui se sont formées, au-delà des limites traditionnelles de la discipline, au sein de l'Union canadienne de géophysique. Il n'y a pas de rapport sur la géodynamique cette année, bien que le projet international sur la géodynamique se poursuive; les études qui en font partie sont convenablement décrites dans d'autres chapitres du bulletin. On a encore inclus un chapitre sur la vulcanologie, mais aucun rapport sur l'océanographie n'est disponible.

Le rédacteur désire rendre un témoignage reconnaissant aux membres de l'Union canadienne de géophysique, de la Division de l'aéronomie et de la physique de l'espace de l'Association canadienne des physiciens, de la Société canadienne de météorologie, de l'Institut canadien des arpenteurs, et du Comité conjoint pour l'hydrologie, qui ont fourni et compilé les chapitres et les bibliographies. Le bulletin a été publié par la Direction de la physique du globe du ministère de l'Energie, des Mines et des Ressources, à la demande du Comité national du Canada de l'Union Géodésique et Géophysique Internationale et le Conseil canadien des sciences de la terre.

Le bulletin peut servir de source pour les rapports nationaux soumis à l'UGGI et aux associations de l'UGGI. Il est très répandu au Canada et à l'étranger. Les demandes pour obtenir des exemplaires individuels et des éditions précédentes, lorqu'il y en a, doivent être acheminées au Secrétaire du Comité national du Canada de l'UGGI, Conseil national de recherches du Canada, Ottawa K1A 0R6. Le bulletin est offert à titre gratuit, mais le Comité national du Canada apprécierait recevoir en retour des rapports semblables de sources nationales ou internationales.

Nous tenons à remercier Md. M. Bradfield, Md. J. Legere et M. E.B. Manchee qui n'ont pas épargné leurs efforts pour contribuer à la préparation des documents pour fins d'impression.

R.M. Farquhar
Rédacteur en chef

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DATA AVAILABILITY FROM THE ARCTIC ICE DYNAMICS JOINT EXPERIMENT (AIDJEX)

Compiled by: E.F. Roots

The Arctic Ice Dynamics Joint Experiment (AIDJEX) was an integrated multi-faceted study of the dynamics of motion of pack ice in the western and central Arctic Ocean. It attempted to couple the forces that influenced the movement of water, sea ice and atmosphere on local and regional scales. The studies were organized jointly by a U.S.-Canadian scientific planning group and coordinated through the AIDJEX planning and operations office at the University of Washington, Division of Marine Resources, Seattle, Washington. Field studies were carried out between 1970 and 1976 culminating in a major year-long occupancy of a number of manned camps on ice floes in the Canada Basin section of the Arctic Ocean from April 1975 to April 1976. Approximately 40 Canadian, American and Japanese scientific agencies or institutions took active part in the experiment. Background information, interim results and discussion or analysis of related or associated data have been made available through the informal bulletin "AIDJEX BULLETIN", of which 35 issues have been released.

An essential feature of AIDJEX has been that all field data obtained shall be freely available to all scientists at cost for legitimate scientific uses. To accomplish this a central Data Bank has been set up and the field data obtained are now being classified and entered into the bank. The following notes describe what is available and how it may be obtained.

A. Introduction

The AIDJEX Data Bank is the primary repository for data acquired on the Beaufort Sea pack ice during the AIDJEX Field Test of 1972 and the AIDJEX Main Experiment of 1975-76. AIDJEX BULLETIN No. 19, March 1973 shows the data sets acquired during the first period. The purpose of this note is to outline the variety of data which have been validated and entered into the AIDJEX Data Bank from the second period. In addition to the source data, there are some post-processed data sets and several supplementary supportive data sets supplied by outside sources.

These data are being used for the analysis of the air-ice-sea interactions and associated phenomena. Many articles published in the AIDJEX Bulletin relate to analyses of these data sets and some of the articles include a brief overview of these actual data.

Data in digital form are stored on magnetic tape and are housed at the Computer Center of the University of Washington. Duplicate copies of these tapes are held at the AIDJEX Office for security. Non-digital data, such as remote sensing data in the form of satellite photographs and sample printouts of various data sets, are also housed at the AIDJEX Office.

Any set of files or subfiles listed below may be obtained by writing to AIDJEX, noting the data files desired and the medium on which it should be produced. Digital data can be provided as a printout, as a set of key-punched cards, or on half-inch, seven-track magnetic tape. These would be accompanied by a narrative description of the file contents and the format of the data sets. The cost of these outputs will be approximately the cost of reproduction and mailing. Supplementary data such as satellite photos or weather maps are available for inspection at the AIDJEX Office during business hours. Copies of these materials are best obtained from the original source.

All comments and inquiries concerning the AIDJEX Data Bank should be addressed to Murray J. Stateman, AIDJEX Data Manager, 4059 Roosevelt Way N.E., Seattle, Washington, 98105.

B. Data Files

1. Position of the manned camps and buoys in latitude and longitude versus time.

Approximately ten positions were calculated each day for each operating station using the Transit Navigational Satellite or the Nimbus F satellite. Data for the manned camps were taken from 10 April 1975 to 20 April 1976. Data for buoys at various locations in the Beaufort Sea were taken from April 1975 up to November 1976. Note that the life-time of most buoys is of the order of six months. These data characterize the motion of the pack-ice in the Beaufort Sea for all seasons of the year.

Data are organized in a time series for each station with a separation marker at the end of each twenty-day period.

2. Smoothed position, velocity, and acceleration for the manned camps and buoys in cartesian coordinates.

Data from file 1 above have been post-processed using a Kalman filter technique. In one form, sorting on time, data from each operating buoy are arrayed together at each three-hour interval. In another form, sorting on station, position and velocity are given as a time series, separately for each station. A variance measure accompanies each element of data to characterize its error.

3. Source Data for RAMS buoys tracked by the Nimbus F satellite

These position data have been provided by the NASA Goddard Space Flight Center. After decoding and editing the Goddard tapes, these data have been incorporated into file 1 above. Data have been acquired since the start of the Nimbus F operation in June 1975. Several land-based RAMS packages are included in order to determine the temporal and spatial accuracy of the tracking system.

4. Rotation of the Manned Camp Ice Floes

The orientation of the ice floes, to which the Navigational Satellite positioning system was aligned, was determined together with the camp position. Each camp azimuth, with respect to true North, has been smoothed for the period 10 April 1975 to 22 April 1976. Angular position and rate of rotation for all camps is given at three-hour intervals in a time-sorted data file together with error estimates for each data.

5. Ice Thickness and Snow Depth

Periodic measurements were made at various sites near the manned camps. Statistical evaluation of ice and snow conditions were made from frequent measurements around a given site. Data are not continuous. Tabulations of available data for the period 10 April 1975 to 29 June 1975 have been published in AIDJEX Bulletin #32 (June 1976). Data to April 1976 is available in a similar form.

6. Ice Surface Profile

One profile was taken using a laser altimeter in the NASA 990 as it travelled a 72 kilometer track between two manned camps. A data point is a height above a reference plane every 0.4 meters along the track. The measurements were made on 24 April 1975.

7. Landsat (ERTS) 1 and 2 Satellite Images

Satellite photos of the Beaufort Sea region have been obtained for qualitative and quantitative analysis from the EROS Data Center. About 1,500 photos taken when visibility and cloud cover permitted are on file. Each photo covers a square region 100 miles on the side. Time periods are the Spring and Fall seasons of 1972, 73, and 75.

8. NOAA-4 and NOAA-5 Satellite Images

Photos of the Arctic from Greenland to the Bering Straits have been received daily from NESS since 2 January 1975. Two images cover the belt between 70° and 80°N latitude. That is, each photo covers a square area about 600 miles on the side. During the period from November through January only IR photos are available, while both IR and visible photos are taken during the rest of the year. These are source data for examining large scale ice movements in the Arctic as well as large scale weather patterns.

9. Surface Level Air Pressure - Derived Data

From the combination of National Weather Service surface pressure maps and pressures measured at scattered points in the Beaufort Sea, two-dimensional pressure contours have been derived for every three-hour interval. These contours are a sixth order polynomial in X and Y, the grid coordinates overlaying the Beaufort Sea region. The grid is rectangular and each element is 75 miles on the side. The coefficients of the polynomial are the data of this file. They can be used to determine the surface pressure at any point in the area at any three-hour interval by translating latitude and longitude of the point to the grid coordinates and employing the polynomial coefficients for the time desired.

To date the coefficients have been calculated for the period 11 April 1975 to 19 July 1975. This work will continue until all coefficients to 30 April 1976 are obtained.

10. Geostrophic Surface Winds - Derived

From the derived pressure data of File 9 above, geostrophic wind speed and direction at grid points and at AIDJEX stations are obtained. There are two separate files with data given every three hours during the corresponding time period.

11. Pressure Charts-Source Data

Surface and 850 mb pressure charts prepared by the National Meteorological Center for the Northern Hemisphere have been received for zero and twelve hours GMT each day since April 1975. These analog charts are used in the derivation of the digitized data of files 9 and 10 above.

12. Surface Level Meteorological Data

Weather stations were operated at each of the AIDJEX manned camps from April 1975 through April 1976. Hourly averages of observed wind speed and direction at ten meters height and air temperatures at two and nine meters height above the surface have been prepared. Time series for each camp are available for the full operating time period of the AIDJEX Main Experiment. There are separation markers between each twenty-day interval.

13. Atmospheric Inversion Levels

Inversion heights in the atmosphere were continuously monitored by Acoustic Radar at the manned camp designated as the main camp. Analog

records were digitized at hourly intervals for the periods 13 April - 1 October 1975 and 5 November 1975 - 18 April 1976. Up to seven distinct inversion heights are given when they exist simultaneously.

14. Ocean Currents - Combined Files for Manned Camps

The manned camps on ice floes served as floating platforms from which ocean currents were measured continuously at depths of 2 and 30 meters. These are currents measured relative to the motion of the ice. Hourly averages of ocean currents combined with hourly geostrophic winds and three-hourly smoothed ice velocity (files 10 and 2), at each manned camp, for the full operating period of the AIDJEX program are available in a single file.

These data are sorted by camp, by time with separation markers between twenty-day intervals.

15. Ocean Currents combined with Position - measured from RAMS buoys.

Two RAMS spar buoys were deployed offshore in the Beaufort Sea in November 1975. They contained sensors which measured ocean currents at depths of two and thirty meters. A magnetic compass heading for the buoy and internal bearing of the current sensors are given with the current data at three-hourly intervals. These data have been combined with buoy position data to allow for absolute current determination. One buoy operated until 1 October 1976 while the other provided meaningful data only until 28 March 1976.

16. Oceanic Mixed Layer Characteristics

The upper ocean mixed layer is defined in depth by the point(s) at which a rapid change in salinity occurs. This layer was measured for surface temperature, surface salinity and depth(s) twice daily at each manned camp. All available measurements (one per day) were published in tabular form in AIDJEX Bulletin #32 (June 1976).

17. Ocean Depth

The depth of the ocean beneath the Main AIDJEX Camp track was measured during two time periods. Acoustic soundings were taken every hour from 25 May to 3 August 1975 and from 18 December 1975 to 25 April 1976. Round trip time of sound travel is given together with interpreted depth.

18. Surface Pressure, Validated, Offshore RAMS Buoys

Four RAMS Buoys deployed offshore in the Beaufort Sea measured surface pressure. These measurements have been corrected for scale and sensor drift and have been smoothed and interpolated to three hourly readings.

Buoy	207	was	operational	from	18	March	1976	to 28 August	1976
"	1015	"	"	"	23	March	1976	to 30 September	1976
"	1245	"	"	"	4	November	1975	to 1 October	1976
"	1416	"	"	"	5	November	1975	to 28 March	1976

The data are sorted by buoy, by time and are merged with buoy position in latitude and longitude.

19. Surface Pressure, Validated, AIDJEX camps and selected buoys

NavSat Systems at the four manned camps and nine Navigational Satellite buoys had pressure sensors to make detailed measurements not specifically included in the surface pressure charts of file 11 above. After appropriate corrections and calibration, these validated measurements were incorporated in the derivation of area-wide geostrophic

winds (file 10). These source data are available together with their geographic position at three-hour intervals. Data are sorted by station. The manned camps were operational from April 1975 to April 1976. Some of the buoys (supplemented by nearby RAMS Buoys) continued to be operational as late as 6 December 1976.

20. Weather Observations - Manned Camps

Hand written weather notes were logged daily by the observers in the manned camps. Wind velocity, surface pressure, temperature, visibility and weather were noted. These data are back-ups for the digitized data in the respective files noted above.

21. Logbook Entries - Manned Camps

Informal notes concerning any events, performance of equipment, changes or calibration of sensors, etc., were recorded by members of the scientific groups. These entries are back-ups to the data collection procedures performed during the main AIDJEX experiment.

C. Data being processed but not yet available

The following data sets are in the process of validation and calibration. They will be added to the AIDJEX Data Bank files and made available to the scientific community together with the files noted above.

22. Pilot Balloon - Wind Speed and Direction

PIBAL measurements using two tracking theodolites were made each day at each manned camp during the AIDJEX Main Experiment.

23. Ocean Current Profile

A current meter was lowered to a depth of 194 meters and raised at a steady rate to determine the stratification of the ocean layers. This measurement was made twice daily at each manned camp. The analog outputs will be digitized to show time, depth, speed and direction at uniform depth increments.

24. Salinity and temperature versus Depth at Manned Camps

Standard STD measurements were made twice daily at each manned camp during the AIDJEX Main Experiment.

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I(A) GEODESY

Compiled by: D.B. Thomson

1. Geodetic Survey of Canada

Extension and densification of the horizontal control network was continued. First-order control field work was concentrated on the acquisition of data for the proposed 1977 Canadian adjustment. Several satellite Doppler stations were tied to the existing network. First-order traversing was carried out in southern Saskatchewan (300 km) and southern Newfoundland (270 km). An accurate network of 13 stations was established upstream from the Manic 3 Dam on the Manicouagan River in Quebec to monitor earth movements (Swanson, 1976). Multi-purpose second-order traversing was done in a 128,000 square km area in the Mackenzie Mountains (southern part of the Yukon-Northwest Territories boundary). Second-order traversing was also established on Vancouver Island and the Queen Charlotte Islands to provide control for mapping and offshore-positioning.

The satellite Doppler framework for Canada (200 to 500 km spacing) was completed with the observation of 27 new stations and the re-occupation of 17 previously established. Of the new stations, 23 were coincident with conventional first-order network points established by triangulation or airborne trilateration (Aerodist). Doppler techniques were also used for positioning marine navigation aids in Senegal, West Africa (3 stations), and for hydrographic control in the northern part of Lake Superior (2 stations). A programme was begun in Alberta and Saskatchewan to provide Doppler stations at 80 km intervals for subsequent second-order densification surveys using Inertial Survey System (ISS) techniques. (cf. next paragraph). Orthometric heights at the Doppler stations were derived using a combination of ellipsoidal heights and geoid undulations.

The ISS was used extensively on various projects. The system mounted in a ground vehicle was used to establish vertical control for the mapping (at the scale of 1:50,000) of Vancouver Island, along some 2800 km of lines to establish elevations at about 8 km spacing. The system was then counted in a helicopter and was used to establish horizontal and vertical control for an area of approximately 48,000 square km in southern Alberta. Within this area, some 450 points were established generally at intervals of one (10 km) and two (20 km) townships. Several Indian Reserves in Alberta were also surveyed with the ISS in the airborne mode. Second-order control was also established in Saskatchewan along a 480 km line running along a highway from North Battleford to Turnor Lake. Some 30 ISS stations were established between 14 Doppler stations. Details about the ISS are to be found in (O'Brien, 1976).

Mekometer measurements were made on existing base lines at Montréal and Chicoutimi, Québec, and on new baselines at Calgary and Edmonton, Alberta.

The Ground Elevation Meter (GEM) was used to establish lower order vertical control in the Lac St-Jean and Montmagny areas of Québec and in many parts of New Brunswick to satisfy both federal and provincial mapping needs.

A total of 20 first-order and 7 second-order astronomical Laplace stations were observed as orientation control for horizontal networks. Also, 10 astrogeodetic deviations of the vertical were determined as part of the programme to determine the geoid in Canada.

Extension and densification of the vertical control network was also continued. A total of 4300 km of levelling was completed. Some 800 km of levelling was carried out from Schefferville to Fort George on James Bay in co-operation with the James Bay Development Corporation. Levelling continued down the Mackenzie River as far as Arctic Red River terminating a 5 year co-operative programme with the federal Department of Public Works. Some 60 km of levelling was done on roads near Yellowknife, N.W.T., and about 670 km along the Alaska Highway in the Yukon Territory. Levelling was done in the Manicouagan River area, Québec, Mica Dam area, British Columbia, and between Campbell River and Gold River on Vancouver Island for the monitoring of vertical crustal movements. Levelling was also done in Newfoundland, Ontario, Manitoba and Prince Edward Island. For further details, see (Babbage, 1976).

Tests were made on two new levels, a Sokkisha B1 and a MOM Ni A31. Further development work was done on the Astro Printer with consequent gains in speed and accuracy for registering transit time of stars. As a result of the project, three units of Model 03 will be made available for production work in 1977.

The reduction of astronomical latitude, longitude and azimuth to the FK4 and CIO systems was continued. Some 305 Laplace stations (at which deviation observations were also made) and 466 additional deviation stations, dating from 1940 to 1974, were processed.

Preparations for the proposed 1977 Canadian adjustment of the horizontal framework continued (McLellan, 1976). The geodetic adjustment programmes GALS and HAVOC were modified substantially in view of the adjustment. The new version of HAVOC is called GANET (Geodetic Adjustment of Networks). Some of the implemented features are in internal overlay structure, dynamic dimensioning of arrays, input capabilities for large groups of correlated position equations and output of statistical information. A test adjustment of the entire horizontal framework and part of the Doppler network was carried out in May using a variation of the Helmert blocking method. This was done with 18 sections in a three-stage adjustment. Preliminary results were satisfactory and extensive post-adjustment analysis was carried out in connection with outliers and sections of the network. Work was also done concerning the error analysis of least-squares adjustment results and the problems associated with the rejection of outliers (Blais, 1976); this study was done from the points of view of approximation theory, statistical and numerical analyses. Other theoretical questions related to least-squares estimation methods such as collocation and self-calibration techniques are also being investigated.

The relation between NWL9D Doppler and Average Terrestrial Systems was studied in view of the use of the Doppler network in the forthcoming adjustment of the horizontal framework (Kouba, 1976a). Study of the satellite Doppler techniques was continued and latest results indicate that a relative accuracy better than 0.5 metre (1σ) can be obtained with simultaneous observations and current hardware and software (Kouba and Wells, 1976; Kouba and Boal, 1976). Research into the determination of heights using Doppler techniques was also continued (Kouba, 1976b).

Research into the determination of the geoid and deviations of the vertical was continued. Comparisons between Doppler derived and Goddard Earth Model 8 (GEM8) geoid undulations showed that the GEM8 geoid was accurate to about 2 m (1σ) in Canada (Lachapelle, 1976a). Subsequently, GEM8 geoid and deviations of the vertical were used to reduce horizontal distances and angles down to the reference ellipsoid for the May test adjustment. A combined

least-square collocation and integral formulae (Stokes' and Vening Meinesz') method was developed to evaluate geoid undulations and deviations of the vertical from a combination of satellite dynamic, surface gravity and astrogeodetic data (Lachapelle, 1976b). Preliminary results showed that accuracies of about 1.5 m and 1.2 arcsecs (1σ) can be anticipated for geoid undulations and components of the deviation evaluated according to that method (Lachapelle, 1976c).

The programme to automate the national Geodetic data file is continuing. About 30 percent of the estimated 190,000 stations in the manual file are compiled on the automated file and about half are validated. Due to advances in computer technology an evaluation of the existing system is being undertaken which may result in updating to new software systems. Approximately 4,000 requests for control survey data were filled via the manual file. Data issued included 6,500 vertical control quadrangle booklets and 450,000 individual pages of control data.

2. National Research Council, Division of Physics

(a) Photogrammetric Research Section:

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

(b) Time and Frequency Section:

Since January 1, 1972, national time services have been operated on atomic time with no frequency offset. The time disseminated, UTC, differs from atomic time, TAI, by an integral number of seconds, and is stepped by leap seconds to remain within 0.7 seconds of the astronomical time UTI. The first leap second occurred at the end of June 1972, and subsequently at the end of December 1972, 1973, 1974, 1975 and 1976.

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

3. Fisheries and Environment Canada, Bedford Institute of Oceanography

(a) Satellite radar altimetry:

Two closely related Canadian GEOS-3 radar altimetry experiments are to compute the ocean geoid in the vicinity of Canada and compare it with other geoids, and to compute tides and mean sea level from altimetry data. Hudson Bay and the Scotia Shelf/Bay of Fundy were selected as the main investigation areas. For Hudson Bay the primary data acquisition period was September to December 1976, during which NASA tracking data was supplemented by Doppler satellite tracking stations in Calgary, Churchill, Great Whale River, Ottawa and Fredericton. For the Scotia Shelf the primary data acquisition period was May to November 1976, during which a series of bottom tide gauges were moored in this area (see below). Software to predict GEOS-3 orbits, and to decode and summarize GEOS-3 altimetry data supplied by NASA was developed. Other participants in this experiment are the Marine Environmental Data Service, Geodetic Survey of Canada, Earth Physics Branch, Shell Canada Resources Limited, University of New Brunswick, Dalhousie University, and the Institut fur Angewandte Geodasie (Frankfurt).

(b) Integrated Navigation:

Work continued on the mathematical design (Wells, 1976a), overall system design, and gathering of test data for development of an integrated navigation system.

(c) AIDJEX:

Satellite positioning data collected during the fourteen month field program of the Arctic Ice Dynamics Joint Experiment (ending May 1976) has been scanned and three periods identified during which the ice "stuck" (moved by less than 100 m over several days), often followed by movements as rapid as 30 cm/sec. Data from these periods will be used to investigate the modelling of slowly deforming networks of satellite tracking stations.

(d) Offshore tidal observations:

As part of a study for the Fundy Tidal Power Review Board, the Tidal Section of the Bedford Institute placed and recovered a total of 15 tide gauge moorings in the Scotia Shelf/Bay of Fundy area, during the period late April to early November 1976. Each mooring was in place from two to three months. The mooring depths ranged from 140 m to 260 m on the Scotia shelf, and up to 50 m in the Bay of Fundy.

(e) Omega measurements in the Canadian Arctic:

Using a cesium atomic frequency standard, "time of arrival" measurements (equivalent to range) of Omega transmissions were made at sea in Lancaster Sound and Baffin Bay. By comparing with Doppler satellite positions (150 m accuracy) and with the Resolute Bay Omega monitor to remove diurnal phase changes, this data will give information on VLF phase propagation.

4. Fisheries and Environment Canada - Canadian Hydrographic Service

This service continues to gather water level records on Canada's coastal and navigable inland waters. The coastal records contribute greatly to sea level studies. Many off-shore records are now being obtained with submerged pressure gauges: since these are not referred to a stable vertical datum, their records contribute only to knowledge of tidal and other fluctuations in level, not to a knowledge of mean sea level. Commencing early in 1977 it is expected that the data bank of world-wide tidal constituents provided by the Canadian Hdyrographic Service and the Marine Environmental Data Service on behalf of the International Hydrographic Organization will be in full operation.

5. Université Laval

Des études ont été entreprises sur les caractéristiques locales du champ de la pesanteur, sur le rôle des surfaces de références dans la géodésie horizontale et sur les relations entre les quantités astronomiques, géodésiques et observées dans les contrôles Laplace.

Une étude sur les méthodes de compensations en étapes des grands réseaux géodésiques a été complétée.

La recherche entreprise en 1975 sur la solution des problèmes géométriques reliés au système de balayeur multispectral des satellites ERTS a été continuée.

Un projet sur l'élaboration et l'évaluation de méthodes de mesures pour l'implantation de tunnels sous le lit du Saint-Laurent a été complété. Les

méthodes qui avaient été élaborées pour résoudre les problèmes de micro-géodésie présentées par ce projet se sont avérées efficaces. Les méthodes de traitement des données et les résultats obtenus seront publiées dans quelques mois.

6. University of New Brunswick

Work was continued on the combination of satellite and terrestrial geodetic networks. The findings and recommendations are reported in (Thomson and Krakiwsky, 1976; Thomson, 1976). A computer program package for rigorous computation of extensive horizontal geodetic networks was designed and described in (Thomson and Chamberlain, 1976). Investigations were continued into the parameterization of geodetic networks unaccounted for systematic errors using combination of satellite and terrestrial geodetic networks.

Investigations were begun into the procedures required for the redefinition of the Maritime geodetic network. A second order horizontal geodetic network, tied to the national framework, is to be used as the positional information base by the Land Registration and Information Service (LRIS) by the provinces of N.B., N.S. and P.E.I.

Research has begun on the design of geodetic networks using interactive computer graphics. A textronics screen is used to display the existing network points and any new points to be determined. Observations are added and real-time computations made (using APL on the U.N.B. IBM/370 computer) of the confidence regions for the new points. The final network design is achieved when the confidence regions reach the design size and shape.

Some initial investigations - mainly literature searches and some simplified computerized simulation studies - were begun on the application of inertial measuring units on geodesy. Results are reported in (Adams, 1976; Dyment, 1976).

Research was continued on the joint project, between the U.N.B., U. of Alberta and the Peruvian Institute of Geophysics, to develop survey methodology for monitoring tectonic movements at high altitudes (4500 m) using geodetic micro-networks. A second set of measurements of the test network, established in Peru, was made during the summer of 1976. Standard deviations of relative displacements of points (11 stations with distances ranging from 200 m to 1500 m) were obtained between 3-6 mm. No displacements larger than their standard deviations were detected.

Work continued in the field of vertical crustal movements using precise relevellings. A map of vertical crustal movements for Ontario has been already compiled. Research is continued on the merits of sea-level records in detecting the vertical crustal movements, using tide-gauges from Eastern Canada.

Investigations on the actual gravity field and levelled heights in Canada were continued. The corrections (due to the irregularities of actual gravity field) to heights based on normal gravity are applied to real levelling lines and loops and the resulting distortions are analysed. The U.N.B. approach for the areal prediction of these corrections was systematically applied to all Canadian areas covered by precise levelling - using actual gravity data based on the up-to-date 1967 International System supplied by the EPB. Results and findings of this research, with the emphasis on the Canadian Precise Level Network, are documented in (Nassar, 1976).

Work continued on the optimal determination of the geoid for Canada with local features. An improvement in the U.N.B. technique for geoid determination is made to obtain optimal solution using all four available sources of information: Doppler derived geoidal heights; the earth's gravitational solution GEM8; the astrogeodetic deflections of the vertical and

the gravity anomalies. An alternative approach to evaluate Stoke's function and carry out the integration over a relatively limited area is also introduced.

7. Energy, Mines and Resources Canada, Earth Physics Branch

(a) Polar Motion Observations

The Earth Physics Branch continued astronomic and satellite Doppler observations at the polar motion observatories near Ottawa and Calgary. The astronomical latitude and rotational time results obtained by the PZT instruments have been contributed regularly to the time (BIH) and polar motion (IPMS) services. The satellite Doppler data have been daily transmitted to the DMATC Polar Monitor Service.

Fully automated, computer controlled satellite data acquisition and communication system has been developed for the Ottawa Tranet station and the station has been moved to its permanent location at Shirleys Bay in December 1976.

Results of simultaneous satellite and astronomical observations at Ottawa show approximately the same dispersion of the mean daily coordinates. The satellite results do not indicate apparent seasonal variations which are characteristic for the astronomical observations. Continued observations are required to determine the differences between the two techniques for polar motion studies.

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I(B) GRAVITY

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Earth Physics Branch,
E.M.R.

1. Introduction

This report has been compiled from information provided by various sources believed to be the principal contributors to gravity investigations in Canada. It should also be noted that a report on the activities in the field of geodynamics carried out by the Earth Physics Branch has also been included in this summary of activities. As with last year's bulletin the summary for geodynamics provides a consolidated report on such activities previously included under the Geodynamics Section.

2. Earth Physics Branch

(a) Gravity Standards

The National Gravity Net inspection and maintenance program continued this year with activities taking place in Northern Ontario, southern Quebec and the central regions of British Columbia. All field work was carried out by geophysical contractors. New station descriptions and gravity values for these areas will be available on request after March 31st, 1977. All national net station descriptions are now being converted to a bilingual format.

Under the auspices of the Pan American Institute of Geography and History a compilation and adjustment of 1005 gravity control stations in Latin America has been completed. A final report will be presented to the Geophysics Commission of PAIGH at the August 1977 general assembly in Quito. Data files and station descriptions from this project will be transferred to a Latin American agency.

The maintenance service for the International Gravity Standardization Net (IGSN71) described in last year's bulletin is now in operation. Activities have been centred on a major update of all IGSN71 station descriptions from material supplied by some 50 agencies around the world.

(b) Gravity Data Base

A new level of the gravity anomaly retrieval system (SYS76) was fully tested, made operational and incorporated into the National Gravity Data Base, resulting in a substantial improvement in quality control and retrieval capabilities.

A commercial data base management system (S2K) has been implemented for the Control Station File which contains all information relevant to the National Gravity Net.

(c) Gravity Data Processing

Efforts have been concentrated on refining the reduction and editing systems for field observations in order to reduce the time interval between the gathering and the dissemination of data. Significant improvements in software, particularly in relation to processing offshore gravity data, have been made in the past year. The introduction of an open file system also contributes to the earlier release of data.

(d) Gravity Map Production

Three open files consisting of anomaly maps and the related digital files were released in 1976:

76-1 Queen Charlotte Sound: approximately 2700 observations released as a Bouguer anomaly map at a scale of 1:250,000.

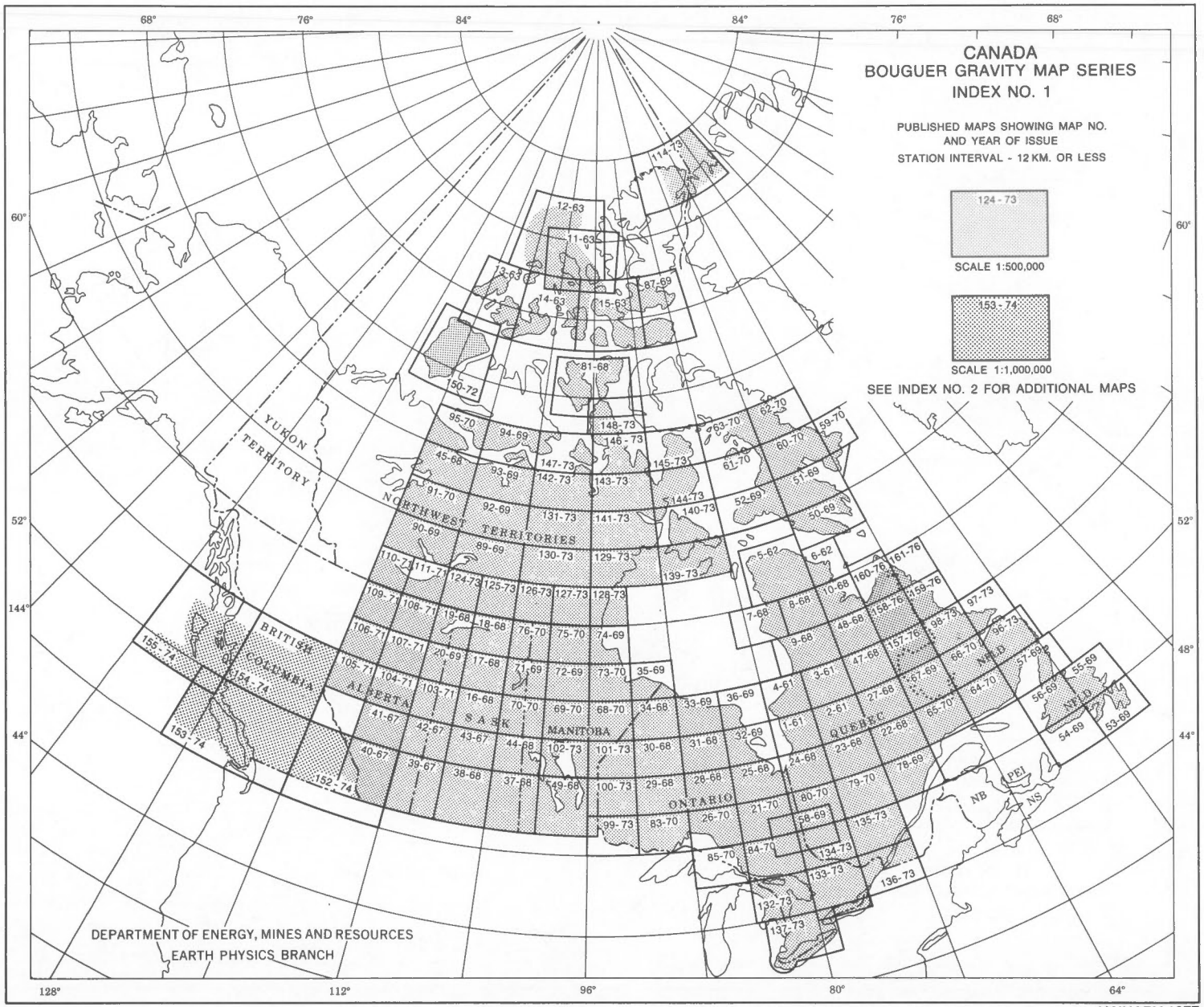
72-2 La Perouse Bank: approximately 2100 observations were compiled and released in the form of separate free air and a Bouguer anomaly map at a scale of 1:250,000.

76-3 James Bay: about 2300 observations were published in the form of a Bouguer anomaly map at a scale of 1:500,000.

(e) Gravity Surveys

A review of gravity mapping in Canada was presented at a symposium on 'Geophysics in the Americas' held at Ottawa and sponsored by the Pan American Institute of Geography and History. The scope was extremely broad and covered all phases of the systematic mapping program for the Canadian landmasses and territorial waters, which is organized and directed by the Gravity Service of the Earth Physics Branch. Following an opening statement of objectives, a brief history of gravity mapping in Canada, punctuated with statistical data, was given. This commenced with reference to the first gravity measurement in 1820 near Winter Harbour, Melville Island by Lieutenant Edward Sabine a member of Sir William Parry's expedition in search of the northwest passage, then moved to a description of the pendulum measurements in the first half of this century, and of the gravimeter surveys in the period 1944-1975. A large part of the presentation was devoted to describing the various gravity survey methods designed to cope with the diverse conditions encountered in the Canadian scene. Four basic categories of surveys are employed: land, ice-surface, underwater and sea-surface. These require a variety of transportation modes, instrumentation and methodology; all of these aspects were reviewed. The specifications for the different survey parameters (station and ship's track spacing, gravity anomalies, vertical and horizontal positioning) and production rates were discussed. In closing this subject a brief outline of recent experimental airborne gravity measurements conducted by the Earth Physics Branch was presented.

Approximately 15,000 line kilometres of dynamic gravity data were observed on two shipborne surveys during 1976. In addition 4600 static


CANADA
BOUGUER GRAVITY MAP SERIES
INDEX NO. 1
PUBLISHED MAPS SHOWING MAP NO.
AND YEAR OF ISSUE
STATION INTERVAL - 12 KM. OR LESS
124 - 73
SCALE 1:500,000
153 - 74
SCALE 1:1,000,000
SEE INDEX NO. 2 FOR ADDITIONAL MAPS
DEPARTMENT OF ENERGY, MINES AND RESOURCES
EARTH PHYSICS BRANCH
JANUARY 1977
YUKON TERRITORY
NORTHWEST TERRITORIES
BRITISH COLUMBIA
ALBERTA
SASK
MANITOBA
ONTARIO
QUEBEC
NFLD
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68°
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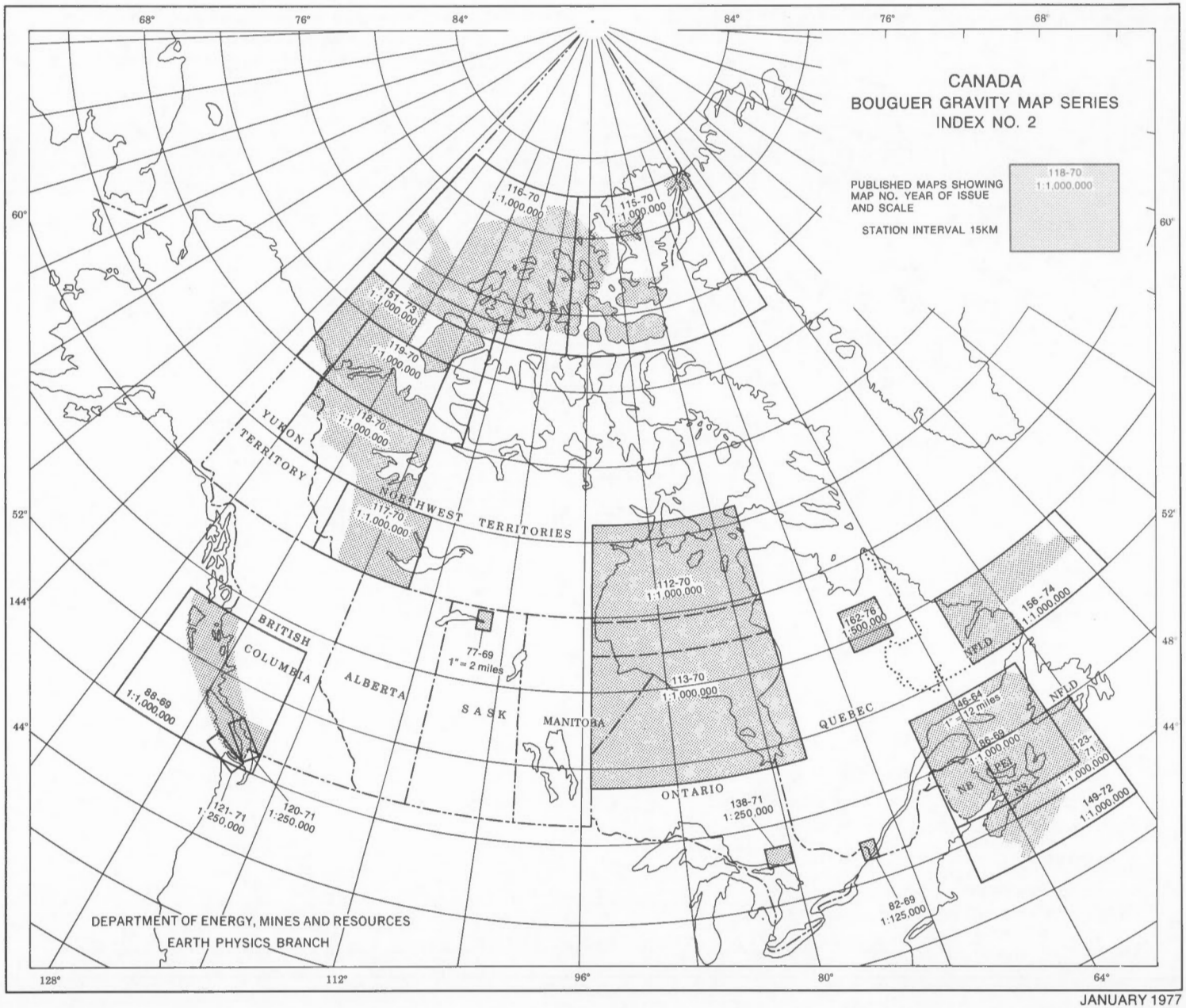
CANADA
BOUGUER GRAVITY MAP SERIES
INDEX NO. 2
PUBLISHED MAPS SHOWING MAP NO. YEAR OF ISSUE AND SCALE
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96°
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116-70
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NORTHWEST TERRITORIES
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113-70
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1" = 2 miles
162-76
1:500,000
156-74
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NFLD
46-64
1" = 12 miles
86-69
1:1,000,000
123-71
1:1,000,000
149-72
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NB
PEI
NS
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BRITISH COLUMBIA
ALBERTA
SASK
MANITOBA
ONTARIO
QUEBEC
121-71
1:250,000
120-71
1:250,000
138-71
1:250,000
82-69
1:125,000
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measurements were made on land and ice-covered coastal areas. The distribution of these data is given in point form below.

(i) *British Columbia*

During parts of May and June about 4500 line kilometres of shipborne gravity measurements were observed from the CSS Parizeau in the coastal area immediately west of the northern part of Vancouver Island. The survey area commences at latitude 49° and terminates at latitude 51°. The survey area extends for a distance of 100 km offshore. Track spacing varied between 5 and 10 km.

A contracted underwater gravity survey adjacent to the westerly margin of Vancouver and Queen Charlotte Islands during August and September observed 290 stations. Average station spacing was 4-5 km.

(ii) *Hudson Bay*

Between mid-July and the end of August, 10,500 line kilometres of shipborne gravity meter measurements were added to the joint Canadian Hydrographic Service, DOE - Earth Physics Branch, EMR multidisciplinary marine survey commenced in 1975. This cruise, aboard the CCGS Narwhal began the interlining phase of the 45 km line spacing completed last year.

(iii) *James Bay*

A helicopter supported party working in cooperation with the Canadian Hydrographic Service and the Ministry of Transport completed, during February and March, the regional gravity survey of James Bay begun in 1975. About 1600 gravity stations and related water depths were observed from the frozen surface of the Bay by contract observers.

(iv) *Northwest Territories*

Great Slave Lake

A contracted survey observed 500 gravity stations on the frozen surface of Great Slave Lake during February and March. The area of the survey covered approximately two-thirds of the lake lying west of a line drawn between Yellowknife and Rocher River on the southeast shore. Station spacing varied between 4 and 6 km. This survey was designed to further a comprehensive geophysical study of the geological structure of this important region of the Canadian Shield.

Beaufort Sea and Amundsen Gulf

Using helicopter support, more than 700 gravity stations and related water depths were observed during March and April on the ice-covered surface of Amundsen Gulf and in the Beaufort Sea adjacent to Banks Island. As in previous surveys station spacing was maintained at 6 km intervals. This survey completed the regional gravity coverage in the general area of the Beaufort Sea and Amundsen Gulf.

(v) *Nova Scotia*

A contracted survey, using vehicle and helicopter support, completed 1600 gravity observations throughout Nova Scotia during August, September and October. Small areas in the Lunenburg area and in the Annapolis Valley were not completed. Average station spacing in the surveyed areas was 6 km.

(f) Gravity Interpretation Studies

In 1976 interpretation studies using gravity and related data were concentrated chiefly in the Arctic, in offshore regions and in the Canadian Shield.

(i) *Sverdrup Basin*

The compilation of Phanerozoic vertical motion data from Arctic regions is virtually complete. Discussion of Arctic evolutionary scenarios with other contributors to a special EPB study is in progress. Chief among the problems at this point are the whereabouts of northern Alaska before Tertiary time, the origins of the Lomonosov and Alpha-Mendeleyev Ridges and the definition of Mesozoic plate boundaries.

(ii) *Beaufort Sea*

Remote sensing (ERTS) imagery has been used to map the distribution of leads in the sea ice over the Beaufort Sea during late February through early April in 1973, 1974 and 1975. A comparison of bearings and speeds of ice movements obtained from these ERTS-based maps with those of geostrophic winds calculated from average daily and weekly atmospheric pressure charts indicates that the ice drifts at about 1/100 of the speed of the geostrophic winds in a direction about 20° to the left of the latter. During early March, 1973, before excessive ice break-up, the sea ice moved slowly, about 0.3 km/day, but during periods of rapid ice-fracturing (March and April 1975) the sea ice moved at rates as high as 18.2 km/day. This study was carried out in support of a proposed seismic gravity profile across the continental shelf to the ocean deep to elucidate the structure in the vicinity of the continental break.

(iii) *Mackenzie Delta, Alaska and Beaufort Sea*

In a discussion of a paper by Yorath and Norris (1975) to be published in the bulletin of the Canadian Society of Petroleum Geology, L.W. Sobczak addressed three main questions: (a) what is the probable primary cause of the positive free air anomalies over the continental break? (b) do the geophysical data support the seaward extension of the Aklavik Arch and the Kaltag Fault system? (c) is there any geophysical evidence to support a Mesozoic spreading centre off the Canadian continental margin? He believes that insufficient attention was given to the inherent ambiguity of the geophysical data and that interpretations other than those offered by Yorath and Norris deserve attention.

(iv) *Arctic Ocean and Surrounding Continental Areas*

Bathymetric and free air gravity maps at a scale of 1:7,500,000 on a polar azimuthal equidistant projection have been prepared for the Arctic region north of 60°N latitude to the North Pole and from 0° to 360° longitude. The bathymetric map was reduced from the American Geographical Society's map compiled by Heezen and Tharp of the Lamont-Doherty Geological Observatory. Unfortunately, investigation showed this map to be in error in different regions of the Arctic and a revision of the bathymetric map is now in progress.

The free air map was compiled using mean free air anomalies (2° longitude x $\frac{1}{2}^{\circ}$ latitude) calculated from more than 119,000 gravity observations which cover about 50% of the area. The other half of the region was covered using the predicted 1° x 1° mean free air anomalies of the Defense Mapping Agency Aerospace Centre

(DMAAC). This map was compared with a satellite free air gravity map using $5^{o} \times 5^{o}$ station values represented by spherical harmonic coefficients to degree 25 to verify the regional character of the gravity field as described by the diverse sources of gravity data used to compile the free air map.

(v) *Amundsen Gulf*

A study of gravity and magnetic data of the Amundsen Gulf confirmed geological estimates of 2 to 6 km of possibly late Precambrian and younger sedimentary rocks beneath Amundsen Gulf. The major gravity and magnetic anomalies are attributed to sources within the Precambrian basement underlying the sedimentary rocks. Northerly trending gravity and magnetic anomalies which terminate along the north shore of the gulf, indicate that northerly trending Archean or Aphebian structures of metavolcanic rocks and granite gneisses which make up the Precambrian stable craton also end at this point. The position of this margin differs from that of geological estimates which suggest that the margin of the stable craton passes through western and northern Banks Island.

A basic to ultrabasic intrusion of possible Hadrynian age 100 km northeast of Darnley Bay is responsible for a 40 mgal gravity anomaly and a 600 gamma magnetic anomaly. Its similarity to the slightly more pronounced Darnley Bay anomaly suggests that both intrusions may be sources of Hadrynian dikes, sills and flows throughout the Amundsen Gulf and surrounding area.

(vi) *Continental Margin of British Columbia*

A review of all the available geophysical and geological evidence along the continental margin of British Columbia strongly suggests that, at least south of 51^{o}, the most reasonable explanation of contemporary tectonics is in terms of continuing subduction of oceanic material beneath Vancouver Island. The evidence for subduction of material during the last ten million years is stronger and quantitative calculations can be made of the extent and thickness of the lithospheric slab of material that has been subducted. Interpretations of the gravity field of the region are proceeding on this basis, noting in particular the probable phase change of oceanic crustal material which may take place at shallow depths and result in high density material. Preliminary results indicate that the gravity field of the area is explicable in this manner and is comparable with gravity fields observed in other subduction zones.

(vii) *Nova Scotian Shelf*

The most notable feature on the Nova Scotian continental shelf is the Orpheus Graben which lies along the Minas Basin - Chedabucto Bay - Orpheus fault zone and which is filled with Mesozoic sedimentary rocks. Many of the basement structural features on the Nova Scotian continental shelf appear to be products of continental collision during the early Paleozoic era while other features are probably due to continental separation in the late Palaeozoic and Mesozoic eras. In particular, the Minas Basin - Chedabucto Bay - Orpheus fault zone was probably initiated in Siluro-Devonian times as the result of the thrusting of the northwestern portion of Africa onto the late Precambrian rocks of the Avalon (Acado-Baltic) Platform of south-eastern New Brunswick, eastern Cape Breton Island and southeastern Newfoundland. Later on, the Orpheus graben was formed along the existing zone of weakness probably in Triassic or Jurassic

time as a result of continental break-up and the formation of the present-day Atlantic Ocean.

(viii) *Eastern Churchill Province*

Preliminary interpretations of alternating regional positive and negative anomalies east of the Labrador Trough in the Churchill Province indicate that they may be related to large-scale block structure within the Churchill crust. This structure is similar to that observed in the Peruvian Andes and it may be possible to use this analogy in reconstructing a geological history of the Trough and adjacent cratons in terms of Andean-type tectonics.

(ix) *Cape Smith Fold Belt*

The deep structure of the Proterozoic Cape Smith fold belt which occurs at the boundary between the Superior and Churchill structural provinces of the Canadian Shield was investigated quantitatively from gravity anomalies. Basaltic rocks of the fold belt are interpreted in part as remanent blocks of oceanic crust tectonically emplaced by obduction on shelf deposits of the ancient Superior margin. They form part of a proposed circum-Superior suture between collided Superior and Churchill cratons. The gravity-derived structure was compared with a conceptual model of continental convergence, collision and suturing.

(x) *Thelon Front*

The Thelon metamorphic front is generally regarded as marking the boundary between the Slave and Churchill structural provinces of the Canadian Shield. It is bounded on either side by coextensive negative (Slave side) and positive (Churchill side) arcuate gravity anomalies. These paired gravity anomalies were interpreted as an edge-effect between juxtaposed crustal blocks of different mean density and thickness. According to this model the density discontinuity penetrates the whole crust and could represent a cryptic suture between collided cratons. The model was compared with a similar model and interpretation derived from the gravity anomaly associated with the Grenville front which marks the boundary between the Superior and Grenville provinces of the Canadian Shield.

(xi) *Labrador Trough*

A study of regional gravity anomalies associated with the Labrador trough in 1975 has been followed by a study of the local anomalies. In the eastern part of the trough positive gravity anomalies correlate with outcrops of basic meta-igneous rocks. Their causative bodies extend subsurface to the east and reach depths of up to 9 km in the central part of the area but are considerably less than the 15-20 km which has been inferred by other workers from surface geological investigations. Small positive gravity anomalies are associated with iron formation. A persistent depression in the observed gravity field over the centre of the trough in the south coincides with deposits of the basal sedimentary unit. Uncertainty in the location of the regional level prohibits accurate thickness determinations of the causative bodies of negative anomalies in this area, but the approximate values of 2-3 km obtained for the basal unit are of the same order as estimates based on geological investigations. In the northern part of the area the causative bodies of the negative anomalies are probably elevated areas of granitic basement. These elevated basement features may be related to a ridge which controlled sedimentation during much of the trough's history.

(xii) *Structural Boundaries in the Shield*

The gravity signature (or type anomaly) at five boundaries between structural provinces in the Shield was derived by averaging profiles. A type crustal model was derived from the type anomaly. It indicated that the younger crustal block was consistently thicker and slightly denser than the older. This consistency was surprising because not only do the structures have a wide geographic distribution but also have vastly different ages. This suggested that similar processes had operated throughout much of Precambrian time. The density discontinuity of the type model penetrates the whole crust and separates cratons of different density, thickness, age and internal structure; it was interpreted as a vestigial suture between collided continental blocks. The model with slight modifications to crustal density and thickness can be applied to all five boundary zones and may apply to other examples in Canada and elsewhere wherever the gravity signature of the type model is recognized.

(xiii) *Morin Anorthosite Complex*

The Morin anorthosite complex of the western Grenville Province is composed of an igneous sequence of anorthosite/leucogabbro-jotunite-quartz mangerite which intrudes granulitic gneisses and metasediments. Separation of the gravity field observed over the complex into regional and residual gravity anomalies by a graphical method reveals that the negative and positive gravity anomalies associated with the Morin complex are superimposed upon a regional negative anomaly which may be caused by a low density mass in the lower crust. There is no evidence of a complementary dense mafic body underlying the complex. The negative residual gravity anomalies over the anorthosite/leucogabbro after removal of the regional field are attributed to an underlying body of relatively pure anorthosite of density 2.69 g/cm^3 intruded into an area whose regional density is approximately 2.78 g/cm^3. This body of anorthosite is divided into two lobes, possibly representing different intrusions separated by a basement ridge, which have the form of irregular sheets 2-4 km thick underlain by thin pipes extending to depths of at least 12 km and which may represent feeders. The anorthosite may extend subsurface to the northwest, northeast and south of the main outcrop. Positive residual gravity anomalies are associated with jotunite, quartz mangerite and metasediments. Jotunite forms a thin surface sheet within the anorthosite/leucogabbro and a more substantial body beneath the southern margin. Quartz mangerite forms an extensive body to the south of the massif and extends beneath the Palaeozoic cover of the St. Lawrence lowlands.

(xiv) *Gow Lake Crater*

Gow Lake, in the Precambrian Shield of Saskatchewan, is roughly circular, 4 km in diameter and has a large central island. Evidence for an origin by meteoritic impact is provided by shock metamorphic effects ranging from planar deformation features in quartz to impact glass, found in brecciated country rocks on the central island. The occurrence of a local negative Bouguer anomaly over the lake is also a characteristic feature of small to intermediate impact structures. The Gow Lake anomaly has an amplitude of about 3 mgal, and is attributed to the breccias and highly fractured country rocks underlying the lake, which model studies indicate extend to a depth of 900 m.

(xv) *Manicouagan Crater*

As part of a combined study of the Manicouagan crater by members of EPB, Johnson Space Center and Lunar Science Institute, Houston an analysis of gravity data from the area has been completed. The crater anomaly extracted from the complex regional field consists of an outer -4 to -10 mgal ring close to the peripheral trough that grades gently upward to a central high of 0 mgal. The interpretation of the data suggests that the depth of excavation of the transient cavity produced by meteorite impact is between 2 and 8 km and most likely between 3 and 5 km.

(xvi) *Combined Analysis of Gravity and Magnetic Anomalies*

Under certain conditions the direction of the total magnetization vector in a magnetized body can be derived from a knowledge of the magnetic and gravity anomalies produced by the body. If the ratio of remanent to induced magnetization (the Koenigsberger ratio) is known (or assumed), the direction of the remanent magnetization vector may also be calculated. This technique was applied to coincident, intense gravity and magnetic anomalies over a Precambrian intrusion of gabbroic anorthosite south of Sept Iles, Quebec. The calculated azimuth and inclination of the total magnetization vector is $-54^{o} \pm 14^{o}$ and $67^{o} \pm 10^{o}$ respectively. Assuming a Koenigsberger ratio of 0.25 as indicated by measurements made on rock samples collected at the margin of the intrusion by the Geological Survey of Canada, the azimuth and inclination of the remanent magnetization vector are -84^{o} and 15^{o} respectively. The corresponding virtual magnetic pole is at 10^{o}N; 155^{o}W and has a standard deviation in latitude and longitude of about 30^{o}. This pole is consistent with palaeomagnetic poles from 1200 to 1500 my old rocks elsewhere in North America but is inconsistent with pole positions of 23^{o}N; 145^{o}E and 1^{o}N; 26^{o}W obtained from AF demagnetized samples at the margin of the intrusion. It is speculated that the direction of magnetization obtained from the combined analysis pertains to the main body of the intrusion and that the magnetization in the marginal samples was acquired later on during early Palaeozoic time.

(xvii) *Global Gravity and Magnetic Anomalies*

A continuing study of global gravity and magnetic anomalies suggests that there may be a fairly close relationship between fluid motions at the surface of the core and lithospheric plate motions at the surface of the earth. The previously described results of a combined analysis of global gravity and magnetic anomalies can be interpreted in terms of an interaction between mechanical and electromagnetic forces in the core. As a result it is possible, with the help of certain additional assumptions, to estimate the velocities of the core surface from a knowledge of the magnetic field. A surprising result is that tangential stresses derived from the velocity field agree quite well with stresses which one might associate with plate motions. Just why this is so is not clear but it is probably a manifestation of convection currents in the mantle.

(g) Physical Geodesy

A computer program was developed to facilitate the representation of the gravity field over portions of the globe by spherical harmonics up to order 200 - a limit set by the memory size of the computer rather than intrinsic to the method. As a test of the program the gravity field over Canada as expressed by $1^{o} \times 1^{o}$ averages was expanded in terms of spherical harmonics to order 200 and compared with the original hand

contoured version of the data set. This high order expansion provided a faithful reproduction of the field both in terms of pattern and magnitude of the anomalies (to within 5% in the case of magnitude).

(h) Dynamic Gravimetry

A paper describing the sea gravimeter trials on the Halifax test range aboard CSS Hudson, 1972 was published during the year. This paper gives an analysis of the results of a comparative test of the LaCoste & Romberg and Askania GSS-2 dynamic gravimeters. The analysis suggests that accuracies as reported in the literature for surveys under optimum conditions in coastal and gulf waters do not necessarily hold for deep-sea operations as experienced in Canada.

An analysis of the results from the 1975 aerial gravimetry test was completed last year. Although the tests were designed largely to evaluate various possible modes of operating the instrument in an aircraft, the results were sufficiently encouraging in terms of accuracy to warrant a more elaborate test. Although much development remains to be done in the way of both technique and instrumentation, the rewards for any successful development could be far reaching in terms of efficient collection of gravity data.

(i) Geodynamics

(i) *Precise Gravity Networks and Profiles*

Precise gravity networks for the measurement of crustal deformation were established in 1976; 1) at the Manic 3 dam in Quebec where seismicity was induced by the filling of the reservoir, 2) in the Charlevoix region of Quebec where there is a concentration of natural seismicity, and 3) along the first order level line from Quebec city to Laurentide Park where there is anomalous vertical crustal movement. The network at Manic 3 consisted of eleven stations and one hundred fifty ties made with each of two LaCoste and Romberg model D gravimeters. This survey marked the first time that a precise gravity network had been established by helicopter using these instruments. At Charlevoix a new fifteen station network involving over two hundred gravity ties made with each of two instruments was established by road. This new network replaces an older one established in 1974. The precise gravity profile from south of Quebec City to Laurentide Park was established in order to provide a basis for a long term study of gravitational effects associated with the vertical movements there. In these networks, the 95% confidence limit for the relative station values was ± 50 nm/s^2 ($\pm$ 0.005 mgal).

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

Over the past few years, techniques for the measurement and analysis of changes in tilt, strain and gravity have been under development at the Earth Physics Branch for the study of earth tides. These techniques are now being applied to the study of crustal movements associated with earthquakes. An underground vault was constructed at Charlevoix, 130 km northeast of Quebec City, principally for the measurement of variations in strain and tilt. A quartz rod strainmeter and an invar wire strainmeter (10 meters in length) as well as three mercury-level tilt meters are operating in parallel in the vault. All instruments are operating at earth tide sensitivity and good tidal records have been obtained for analysis for possible changes in tidal amplitudes. Permanent and simultaneous offsets in both strain and tilt have been identified and are being studied with respect to local seismicity. These variations in crustal dimensions are being studied in conjunction with continuous

measurements of tidal gravity, resistivity, seismic velocity, changes in water levels and gravity networks.

Studies of water level variations in a well near Ottawa have demonstrated that a 200 to 300 meter thick surface layer is decoupled from the normal crustal variations in volumetric strain. Whether this is a general result for the area is being tested by measurements in other wells.

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

The nominal objective of this investigation is the determination of the amplitude and phase of the tidal displacements of the earth's surface. One year of laser ranging data to GEOS-3 from the three stations of the calibration area (Goddard, Grand Turk and Bermuda) has been received from NASA. Work to date has proceeded in two complementary directions; 1) the development of methods designed to minimize the effects of unknown satellite dynamics using simulated laser data, and 2) the fitting of real laser data to the dynamic model incorporated in the computer program GEODYNE.

(iv) *Measurement of Ocean and Ice Dynamics*

Gravity, magnetic field, and ocean depth recordings commenced in December 1975 and ocean and ice tilt measurements in March 1976 were carried out until the end of the AIDJEX project in May. These measurements were made out from a floe station in the Beaufort Sea. During an unusually calm 20-day period in February, when the ice floe remained stationary, the gravimeter records clearly showed the variations due to the ocean and earth tides. From these records it has been possible to determine the amplitude and phase of the three main ocean tide constituents in that part of the Beaufort Sea.

Ocean tilt measurements showed fluctuations of the slope of the ocean surface in the 15 microradian range while on the average the ocean tilted down to the NW by about 10 microradians.

Ice tilt measurements showed that short period tilt changes (30 microradians) are related to the drift velocity of the ice, whereas long period changes (100 microradians) are due to the shifting of the snow load.

(v) *Polar Motion Observations*

The Earth Physics Branch continued astronomical and satellite Doppler observations at the polar motion observatories near Ottawa and Calgary. The astronomical latitude and rotational time results obtained by the PZT instruments have been contributed regularly to the international time (BIH) and polar motion (IPMS) services. The satellite Doppler data have been transmitted daily to the DMATC Polar Monitoring Service.

A fully automated, computer controlled satellite data acquisition and communication system has been developed for the Ottawa TRANET station and put into operation at the permanent station site at Shirleys Bay in December 1976.

Results of simultaneous satellite and astronomical observations at Ottawa show approximately the same dispersion of the mean daily coordinates. The satellite results do not indicate apparent seasonal variations which are characteristic for the astronomical observations. Continued observations are required to determine the differences between the two techniques for polar motion studies.

3. Atlantic Geoscience Centre

(a) Hydrographic-Geophysical Surveys:

The hydrographic-geophysical surveys, a cooperative project with the Canadian Hydrographic Service, Department of Fisheries and the Environment, were continued this year on the charter vessel M/V Martin Karlsen. The survey's prime target was Saglek Bank off the coast of northern Labrador and approximately the southern three quarters of the Bank were surveyed including lines at 5 mile spacing out to water depths of 3000 m in Labrador Sea. While ice conditions were adverse over Saglek Bank during the early portion of the field season, further detailed coverage was obtained northeast of Newfoundland, interlining the area covered during the 1975 field season. Less than 24 hours of survey time were lost due to equipment malfunction or to bad weather and, since two Askania Gss-2 gravimeters were operated, it is anticipated that there will be very few data gaps in the final file of data from the cruise. Procedures were developed during last winter with regard to the handling of data from the two meters in order to eliminate the cross-coupling errors to which they are prone on a ship the size of Martin Karlsen. Data analysis this year is therefore anticipated to be less troublesome.

Data from the 1975 Martin Karlsen survey northeast of Newfoundland and on the southern part of the Labrador Shelf were compiled on contract and maps of Bouguer and free air gravity anomaly (together with magnetic anomaly and total field) were prepared for twelve Natural Resource Map areas. Following discussions with users of Natural Resource Maps in Calgary, it was decided that a more timely release of the data would be attempted by putting both draft copies of the maps and their corresponding digital data files on Open File through the Geological Survey of Canada as soon as possible after their preparation. The draft maps will not contain any of the "marginal note" data, such as gravity base stations and their values but these will be available on the final published maps which will continue to be produced through the Canadian Hydrographic Service. The digital data from the 1975 Martin Karlsen survey was released in mid-January 1977 with the draft maps being released shortly afterwards.

As the multiparameter surveys have progressed northwards, analysis of the dense data coverage substantiated our suspicions from work in the Arctic that the calibration constants of our gravimeters were incorrect. Calibration of two of our gravimeters was therefore carried out in the spring of 1976 over a gravity range equivalent to that between Dartmouth and Resolute. The dense coverage of gravity base stations along easily navigable roads in Europe and the requirement of colleagues from the German Hydrographic Institute to calibrate two of their Gss-3 gravimeters resulted in the calibration being carried out between Eibsee in the mountains of southern Germany and Hammerfest in northern Norway. The German Hydrographic Institute provided excellent logistical support for the project and the calibration was a great success. The calibration factor of our oldest gravimeter was found to be in error by 3%, in agreement with that deduced empirically from the earlier network comparison between data collected on different surveys. Where such errors had been significant in older surveys, empirical corrections had been made for them so that published Natural Resource Maps should not be in error. As a result of this calibration and the availability offshore of seafloor gravity base control points established by Earth Physics Branch, our "ground truth" problems, which would have increased as the surveys proceeded northwards, should be minimized.

(b) Other Surveys:

The major AGC cruise of the year was in the Arctic, and the prime geophysical survey portion of the cruise was in Baffin Bay where several

seismic, magnetic and gravity profiles were run to determine crustal structure of the area (see SPEI section). More lines than expected were run in Labrador Sea because CSS Hudson had to return to St. John's to replace a propeller lost in the ice during the northern survey.

Martin Karlsen also carried out a Dalhousie-AGC survey in the Newfoundland basin. Unfortunately this survey was carried out at the end of the field season so that, even with two gravimeters onboard, the gravity data were of poor quality.

(c) Interpretation:

Although modelling techniques have become more and more automated and sophisticated, most interpretations rely on the "Talwani 2-D modelling program" (or some direct descendant) to provide at least an initial model of the body required to fit an observed anomaly. Several attempts have been made to produce an interpretation program that could be run on-line, interactively. This task was half-completed at AGC using a mini-computer, but now a completely interactive program has been developed for running on the CDC 6400 at Dalhousie University, which can be accessed by a CRT remote terminal. Both gravity and magnetic profiles may be stored in order that the model deduced will account for both anomalies. The cost of running the program at Dalhousie is quite low, an entire morning spent in the production of a model satisfying both parameters costing of the order of ten dollars. Details of the system will be published in the near future.

4. Nova Scotia Research Foundation Corporation

Lack of financial support severely reduced in-house gravity activities.

The gravity data reduction, storage and retrieval system was converted and upgraded to run on the Dalhousie University CDC computer. The data reduction program can now use the 1967 International Gravity Formula and the 1974 adjusted National Gravity Net.

Some gravity stations were measured over a frozen lake on a potash prospect in New Brunswick for a commercial client. Computerized gravity interpretations of the results were carried out.

5. Ontario Division of Mines

The gravity-magnetic susceptability survey over the Red Deer metavolcanic metasedimentary belt, District of Kenora was carried out during the summer of 1976 (Gupta & Wadge, 1976). The objectives of the survey were to outline the deeper geological and structural characteristics of the belt to permit interpretations of its configuration in the third dimension and to collect data on the magnetic susceptability of the various rock units for improved interpretation of aeromagnetic data. The survey area is bounded by latitudes $50^{\circ}30'N$ and $51^{\circ}22'W$ and longitudes $93^{\circ}15'W$ and $94^{\circ}30'W$ covering an area of approximately 8500 km^2. A total of 2471 gravity stations were established using 3 LaCoste & Romberg gravity meters. About 1300 density measurements on rock samples were collected from the survey area. A detailed gravity profile was obtained along the Nungesser Road extending north from Highway 125 to the Berens River; 125 gravity stations over a distance of 100 km were established along this road.

6. Memorial University of Newfoundland

During 1976 approximately 150 new gravity stations, with a mean spacing of 2 km, were established in Newfoundland by personnel of the Physics Department, under three projects; 1) the Plutonics Study Group of the International Geological Correlation Project, in the Carmanville - Aspen Cove area north of

Gander (30 stations), 2) profiling along roads from Gander to Carmanville and from Gander Bay to Port Albert (47 stations), for the purpose of tying Project (1) to the Notre Dame Bay survey (C.G.B., 1974, 1975; Miller and Deutsch, 1976), and 3) a profile of 77 stations located at newly established geodetic bench marks along the Baie d'Espoir highway from the Trans-Canada Highway to the power station near St. Albans, south-central Newfoundland. Interpretation of the results from these projects is under way.

In cooperation with the Earth Physics Branch a base network from Gander to Bishop's Falls was resurveyed to tie the Notre Dame Bay data of Memorial University to the national network. A calibration line near St. John's was also established. A Bouguer anomaly map of the Notre Dame Bay region, to be published in the Earth Physics Branch Gravity Map Series, is in preparation.

7. Dalhousie University

A re-interpretation of the gravity data over the Nova Scotia granitic batholith has been made, using as a guide to models the results of recent petrological work on these rocks. Studies are continuing of the gravity field over selected regions (such as the meta-sediments between granite bosses, and particular phases of the granitic rocks).

8. University of Saskatchewan

Gravity investigations during this year were limited to a student program in which about a hundred gravity and magnetic stations were read in an area 30 miles east of Saskatoon. The area contains a solution collapse structure related to the Prairie evaporite formation. This is the second year in which students have carried out an investigation of that feature. They will also do a seismic survey and submit a report for credit for a university class.

9. Université Laval

Avec l'aide d'un groupe d'étudiants sous-gradués et de deux étudiants gradués (A. Grenon et J. Beaudin), M.K. Séguin a entrepris d'effectuer les corrections topographiques et la mise en plan de toutes les données gravimétriques existantes au début de l'année 1976 dans les régions du Mont Albert et de New Richmond-Hamilton (Baie des Chaleurs) en Gaspésie. On est ainsi parvenu à réaliser une carte de Bouguer utilisable à des fins d'interprétation géologique. A l'aide de calculatrice électronique et d'un écran cathodique d'affichage, on construit des modèles géologiques et la réponse gravimétrique du corps géologique sélectionné est comparée aux valeurs observées de Bouguer; l'écart-type est alors calculé. On est ainsi parvenu à obtenir un modèle géologique optimal de la masse ultrabasique du Mont Albert. On essaie actuellement de simuler un modèle de l'hypothétique ligne "Baie Verte-Brompton" au nord de la Baie des Chaleurs.

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(a) Open Files

Open File of the Earth Physics Branch No. 76-1. Gravity Data Queen Charlotte Sound, Latitude: 51°00' - 52°00', Longitude: 128°30' - 131°00'.

Open File of the Earth Physics Branch No. 76-2. Gravity Data La Perouse Bank, Latitude: 47°45' - 49°15', Longitude: 124°30' - 127°15'.

Open File of the Earth Physics Branch No. 76-3. Gravity Data James Bay, Latitude: 51°00' - 55°00', Longitude: 78°30' - 83°00'.

II SEISMOLOGY AND PHYSICS OF THE EARTH'S INTERIOR

National Reporter: E.R. Kanasewich

1. Canadian Seismograph Stations

The seismograph facilities administered by the Earth Physics Branch of the Department of Energy, Mines and Resources, Ottawa, are listed in Table 1 below. A regional station at La Grande 2 (LGQ), Quebec, was opened on August 3, 1976. Both the Eastern and Western Canadian Telemetered Networks, denoted ECTN and WCTN respectively, operated continuously throughout 1976. Pender Island (PIB) was installed on November 1, 1975, and completes the four-station configuration of WCTN.

Table 1 Canadian Seismograph Stations

	STATION CODE	STATION	LATITUDE N	LONGITUDE W	COMMENT
		Standard Stations (Energy, Mines and Resources)			
1.	ALE	Alert, N.W.T.	82.48	62.41	
2.	BLC	Baker Lake, N.W.T.	64.32	96.02	
3.	EDM	Edmonton, Alta.	53.23	113.36	University of Alberta
4.	FCC	Fort Churchill, Man.	58.76	94.09	
5.	FFC	Flin Flon, Man.	54.73	101.98	
6.	FRB	Frobisher Bay, N.W.T.	63.74	68.55	
7.	FSJ	Fort St. James, B.C.	54.44	124.26	
8.	INK	Inuvik, N.W.T.	68.29	133.50	
9.	LHC	Thunder Bay, Ont.	48.42	89.27	
10.	MBC	Mould Bay, N.W.T.	76.24	119.36	
11.	MNT	Montreal, P.Q.	45.51	73.63	
12.	OTT	Ottawa, Ont.	45.40	75.72	
13.	PHC	Port Hardy, B.C.	50.71	127.44	
14.	PNT	Penticton, B.C.	49.32	119.62	
15.	RES	Resolute, N.W.T.	74.69	94.91	
16.	SCH	Schefferville, P.Q.	54.82	66.79	
17.	SES	Suffield, Alta.	50.40	111.05	
18.	STJ	St. John's, Nfld.	47.58	52.74	
19.	VIC	Victoria, B.C.	48.52	123.42	
20.	YKC	Yellowknife, N.W.T.	62.48	114.47	
		Regional Stations (Energy, Mines and Resources)			
21.	CHQ	Charlesbourg, P.Q.	46.89	71.30	
22.	HAL	Halifax, N.S.	44.64	63.60	
23.	IGL	Igloolik, N.W.T.	69.38	81.80	
24.	LGQ	La Grande, P.Q.	53.69	77.72	New August 3, 1976
25.	MCC	Mica Creek, B.C.	52.05	118.59	
26.	PBQ	Poste de la Baleine, P.Q.	55.28	77.74	
27.	POC	La Pocatière, P.Q.	47.36	70.04	
28.	QCC	Queen Charlotte, B.C.	53.26	132.09	
29.	QCQ	Québec City, P.Q.	46.77	71.28	
30.	SIC	Sept-Iles, P.Q.	50.17	66.74	
31.	SUD	Sudbury, Ont.	46.47	80.97	
32.	UNB	Fredericton, N.B.	45.95	66.64	
33.	WHC	Whitehorse, Yukon	60.74	135.10	
		Eastern Canadian Telemetered Network (ECTN) (Digital Recording, Single Component) (Energy, Mines and Resources)			
34.	MIQ	Maniwaki, P.Q.	46.37	75.97	
35.	MNQ	Manicouagan, P.Q.	50.53	68.77	
11.	MNT	Montréal, P.Q.	45.51	73.63	
12.	OTT	Ottawa, Ont.	45.40	72.72	
		Western Canadian Telemetered Network (WCTN) (Digital Single Component Recording) (Energy, Mines and Resources)			
36.	HYC	Haney, B.C.	49.27	122.57	
37.	PIB	Pender Island, B.C.	48.82	123.32	Installed November 1, 1975
38.	ALB	Port Alberni, B.C.	49.27	124.82	
19.	VIC	Victoria, B.C.	48.52	123.42	

Table 1 (continued)

	STATION CODE	STATION	LATITUDE N	LONGITUDE W	COMMENT
		Yellowknife Array, N.W.T.			
		19 elements of short-period vertical recording (Analog Telemetry) 3 elements of long-period vertical recording			
39.	YKA	array Yellowknife	62.493	114.605	Centre
		Mica Dam, B.C. Telemetered Array (Analog Single Component) (University of British Columbia)			
40.	BLU	Blue River, B.C.	52.1533	119.2763	Helicorder
41.	MCC	Mica Creek, B.C.	52.0517	118.5853	
42.	CUM	Mt. Cummins, B.C.	52.0869	118.2117	
43.	DAI	Mt. Dainard, B.C.	52.1986	118.3845	
44.	TAB	Tabernacle Mtn., B.C.	51.7512	117.7617	
45.	THO	Mt. Thompson, B.C.	52.6892	119.1208	
		(University of Manitoba)			
46.		ACTIVE SEISMIC STATION AT STAR LAKE, WHITESHELL PROVINCIAL PARK, MANITOBA, consists of one short-period cluster (Willmores) and one vertical-long period record on analog tape. The remaining two long period components will be added this year.			
		(University of Western Ontario)			
		Seismic array recording on FM analog tape.			
47.		LONDON (LND)	43° 2.4'N	81°11.0'W	
48.		DELAWARE	42°51.5'N	81°23.4'W	
49.		ELGINFIELD	43°11.6'N	81°18.9'W	

A temporary four-component array has been operated near Windsor, Ontario, since September 1976 (see section 2a) and a temporary six-component telemetered array has been operated around the Manic 3 reservoir in Quebec (see section 2b).

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

Several Canadian universities operate temporary or semi-permanent seismograph stations.

2. Canadian Seismicity

(a) Canadian Earthquakes

(i) *Preliminary Summaries, Catalogues and the Earthquakes of 1975 and 1976*

The EPB prepares and distributes to interested organizations preliminary bi-monthly summaries of all Canadian earthquakes approximately 6-9 months in arrears. Currently, the months of May-June 1976 are being analysed, and the summary will be distributed in January, 1977. The purpose of the lists is to provide interested organizations with a complete (but not final) picture of Canadian earthquakes in as short a time span as possible, and to allow Canadian data on all Canadian earthquakes to be included in the International Seismological Centre's world-wide bulletins.

Those organizations interested in receiving such 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 now routinely monitors the telex data on earthquakes sent daily by the operators of the Canadian Seismograph Network for the purpose of detecting and locating the larger earthquakes anywhere in Canada on a current basis. Present procedures allow the detection and location of earthquakes of magnitude 4½ 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. Information on such events may be obtained by contacting the Division of Seismology and Geothermal Studies, Earth Physics Branch, Department of Energy, Mines and Resources, Ottawa, K1A 0Y3.

The Canadian Earthquake Catalogue for the year 1972, the last of the backlog catalogues, will be published early in 1977. The Canadian Earthquake Catalogue for the year 1975 is in the final stages of preparation and is also scheduled for publication early in 1977.

The largest Canadian earthquakes of 1975 occurred on March 8 at 05^h20^m (all times GMT) on the western side of Axel Heiberg island (M_L5.2), on March 31 at 05^h48^m on the western side of Vancouver Island (m_b5.3), on June 14 at 20^h50^m in the Beaufort Sea (m_b5.3), on June 30 at 18^h48^m on Baffin Island (m_N5.2) and

on October 6 at 22^h21^m in the Atlantic Ocean south of Newfoundland (m_b 5.2).

The March 31 Vancouver Island earthquake was felt with maximum intensity of IV on west-central Vancouver Island. On July 12, at 12^h37^m, an earthquake (m_b 4.3) in western Quebec near Maniwaki was felt with maximum intensity IV, and on November 30 at 10^h48^m a M_L 4.9 earthquake in Georgia Strait between Vancouver and Nanaimo was felt with maximum intensity V-VI.

The largest Canadian earthquakes in 1976 to date (13 December) occurred on February 19 at 04^h55^m (all times GMT) in the northern Yukon (m_N 5.0), February 23 at 15^h14^m in Queen Charlotte Sound (M_L 6.1), May 16 at 08^h35^m in Georgia Strait near Pender Island, B.C. (M_L 5.2) and on November 12 at 14^h47^m on northern Baffin Island (m_N 5.3). The Pender Island earthquake on May 16 was felt strongly on the Gulf Islands, southern Vancouver Island and the B.C. lower mainland as well as northwestern Washington State.

A m_N 4.4 earthquake on October 23 at 20^h58^m in the lower St. Lawrence valley was felt to distances of 150 km in south-eastern Quebec and Maine, U.S.A. Preliminary information on this event suggests a mid-crustal focus in the middle of the St. Lawrence River between St. Simeon and Riviere-du-Loup, Quebec. The maximum intensity experienced from this event was V in St. Simeon where stock was knocked from the shelves in the local stores. No instances of damage have been reported.

A series of tremors was felt in the southern Windsor-LaSalle area, Ontario, in February, March, April, June, July and September, 1975, and again in February, 1976. Consequently, EPB has operated a four-component array underground in the Ojibway Mine of the Canadian Rock Salt Co. in Windsor since September 1976. Although the high noise conditions prevalent in the urban area of Windsor-LaSalle prohibit the use of micro-earthquake seismographs on the surface, underground operation of seismographs with gains up to 100K for periods less than 1 sec., even close to the on-going mining operations, is possible. A spread of about 2 km N-S and 1.5 km E-W has been obtained with the Ojibway Mine array, which will allow any subsequent tremors to be located to an accuracy of about 600 m. To date (13 December 1976), no tremors have been reported in the Windsor-LaSalle area since February, 1976.

(ii) *Special Studies*

The 1975 meeting of IASPEI's Commission of Practice at Grenoble, France, set up several working groups to study various aspects of the problems of magnitude determination. A preliminary survey of the local magnitude practices of some 27 seismological institutes in North, Central and South America has now been completed by R.J. Wetmiller (Canada) and W.H.K. Lee (U.S.). The survey indicates that about one-half of the institutes use the duration method to estimate magnitudes while the other half use the amplitude or the amplitude/period ratio. The duration method is favoured for very local earthquakes including micro-earthquakes of very high frequency content, while the amplitude or amplitude/period ratio method is favoured for more distant local earthquakes, particularly in continental areas where the longer periods of Sg or Lg permit accurate determination of the period. The type of instrument employed also appears important in choosing a particular method of magnitude determination. The results of this and similar surveys for other areas of the world will be published by IASPEI in the near future.

D.H. Weichert and R.B. Horner studied the potential contribution of the Yellowknife array to the EPB detection and location capability for Canadian earthquakes. The most important contribution is found for the Yukon - Mackenzie region, where the location threshold can be lowered about one magnitude unit. Detailed results were presented at the eleventh Mathematical Geophysics Symposium of IUGG.

(iii) *Eastern Canada*

G. Leblanc and G. Buchbinder have further analyzed data from the 1974 La Malbaie experiment, described in the 1975 CGB. They have now concluded, on the basis of the focal depth distribution and the fault-plane solutions, that the seismicity may be related to Logan's feature. They also maintain that the Charlevoix circular structure can possibly influence the extent of the active zone. The completed study is now in press.

A.E. Stevens has re-examined the catalogued location and magnitude of 13 instrumentally-recorded earthquakes that occurred in the La Malbaie, Quebec, region from 1930 to 1952. This group included all of the seven large shocks (mag. $\geq$5) in this period. The remaining six events were either foreshocks or aftershocks. The locations of five events were significantly revised; the magnitude of one event (Oct. 1952) was reduced by one-half unit.

The most significant result of the re-examination of location is that six of the earthquakes were shown to have occurred near Baie-St.-Paul and seven near Riviere-du-Loup. These two epicentral areas are at the opposite ends of the 70 km zone of seismic activity outlined by the EPB micro-earthquake field studies of 1970 and 1974. In fact, all the large earthquakes in the La Malbaie region in the period 1930 to 1976 appear to have occurred only at the two extreme ends of the active zone. This relation may extend back as far as 1924. Minor activity has occurred throughout the zone.

(iv) *Central Canada*

Four earthquakes were located in southern Saskatchewan during 1976. Two minor earthquakes located near Radville in March were strongly felt over small areas of perceptibility. The first of these events on March 23, magnitude 3.2, reportedly caused slight damage. The second on March 25 was magnitude 3.5. On November 7, a magnitude 3.1 earthquake located near Esterhazy was slightly felt at Yarbo and by some miners underground in the International Minerals and Chemicals potash mine. The radius of perceptibility appears to have been no more than a few kilometers. One other minor earthquake, magnitude 2.3, was located northwest of Humbolt in May. It was not reported felt. R.B. Horner is beginning a study of the seismotectonics of southern Saskatchewan. The correlation of these events with the area underlain by the Prairie Evaporite and, in some cases, associated collapse structures could be of particular significance to potash mining or the possible storage of nuclear wastes in salt caverns.

(v) *Western Canada*

The December 14, 1872 earthquake, which was felt over a large area of the Pacific coast, has again been studied by a Panel and a report has been prepared.

An extensive review and analysis of the seismicity of western Canada is being made by W.G. Milne, G.C. Rogers, R.P. Riddihough and R.D. Hyndman. The distribution and statistics of the earthquakes will be used to elucidate the tectonics of the region.

G.C. Rogers has been studying two recent felt earthquakes which occurred in the Strait of Georgia. The Nov. 30, 1975 magnitude 4.8 event has a thrust faulting mechanism on an east-west oriented fault and an unusually long sequence of aftershocks. The May 16, 1976 magnitude 5.3 event has a focal depth of 60 kilometres and no detectable aftershocks.

G.C. Rogers has also been studying the magnitude 7.3 British Columbia earthquake of 1946. An isoseismal map has been compiled which confirms a large magnitude for the event. The epicentre has been re-located on to Vancouver Island and the focal depth has been confirmed to be shallow. An alternative P nodal solution has been calculated which indicates strike-slip faulting. H.S. Hasegawa and G.C. Rogers are now working jointly on a more complete study of this earthquake. Refinements are being undertaken on the preliminary work; this refinement includes the incorporation of layering in the residual ground deformation calculation and the re-examination of original records for magnitude and seismic moment determinations.

R.D. Hyndman and G.C. Rogers, in collaboration with D. Barrett of the Bedford Institute, deployed ocean bottom seismometers in the Explorer Ridge area during the summer of 1976. Over 1000 events were recorded, of which 100 were locatable; the largest event, of magnitude 5, can be used as a master event to calibrate shore stations. The events located by the ocean bottom seismometers lie closely along ridge and transform segments, in contrast to the scatter of epicentres derived from shore stations.

(vi) *Arctic*

The study of northern Canadian seismicity by P.W. Basham, D.A. Forsyth and R.J. Wetmiller has been completed. It is concluded that structures formed or reactivated by Palaeozoic and later orogenic phases are continuing activity in response to the contemporary stress field. Possible zones of Cenozoic movement show pockets of high seismic activity but important gaps in the trends remain. Epicentre clusters in the Beaufort Sea and offshore of Ellef Ringnes Island are distributed mainly over the seaward gradient of elliptically shaped free air anomalies, indicating seismic adjustment in basement structures to uncompensated wedges of Recent-Tertiary sediments. Seismicity around much of the Baffin Island-Foxe Basin block shows a significant correlation with the interval of isostatic equilibrium between broad areas of current post-glacial uplift.

H.S. Hasegawa has just completed a draft of a study of the focal parameters of four Arctic earthquakes that belong to the Byam Martin earthquake swarm in the Sverdrup Basin. Preferred fault plane solutions strike, in en echelon fashion, along the axis of the Sverdrup Basin on steeply dipping fault planes. All four have dextral strike-slip motion; three of the four have appreciable normal dip-slip components. Surface wave analyses indicate shallow (upper crust) focal depths. Aftershock activity is taken to indicate fault dimensions of a few tens of kilometers; based on these, stress drops are of the order of a few tens of bars. The deviatoric pressure is in the NE direction and the tension, in the NW direction.

(b) Strong Motion and Seismic Risk

EPB personnel have continued their work on the Canadian Nuclear Association Subcommittee to draft a CSA Code on "Seismic Design Requirements for CANDU Nuclear Power Plants". This code is now in second draft form and is expected to be issued for trial use in 1977. The Branch continues to provide advice to the Atomic Energy Control Board, to the

power utility companies and to other agencies on seismological investigations related to nuclear power plant siting. Work with the joint AECL/EMR Committee on geological storage of radioactive waste also continues and investigations of potential sites will include monitoring of low-level earthquake activity and studies of seismic wave propagation properties of the site.

Research is continuing on attenuation curves of seismic acceleration and velocity amplitudes for western and eastern North America. A revised set of curves has been used to determine acceleration and velocity ground amplitudes with an annual probability of exceedence of 0.01 for the region surrounding the Strait of Georgia in British Columbia. Recent data added to the set have produced a somewhat higher level of acceleration than previously used for the National Building Code. The levels of acceleration have been calculated for sites along the international boundary for comparison with the United States zoning map which is being developed.

P.W. Basham, D.H. Weichert and M.J. Berry are undertaking a study of the seismic risk in eastern Canada and are deriving design basis seismic ground motions at low probabilities of exceedence as a demonstration of the procedures contained in the nuclear power plant seismic design code. Eastern Canada has been divided into "zones of earthquake occurrence" with associated magnitude recurrence equations that can be employed to derive design ground motion for any site in the region on the basis of probabilistic design earthquakes for selected probabilities of exceedence. The lack of a basic understanding of the seismotectonics of eastern Canada suggest this topic as one of the most important for future research.

D.H. Weichert made a study of the methodology of seismic risk estimation in Canada. A paper was given at CAP.

D.H. Weichert also joined the investigation team of the Earthquake Engineering Research Institute (EERI) after the Guatemala earthquake. This observer mission was arranged in the framework of contingency planning for the role of EPB in a major Canadian earthquake scenario.

G. Leblanc and F. Anglin have continued their surveillance of the local induced seismicity in the Manic 3 reservoir using data from the MNQ station together with data from three portable seismometers deployed in the active region for a period of five months after the main event. About 900 microearthquakes were detected and 51 of them located in a region of the reservoir nine kilometers upstream from the Manic 3 damsite. In September 1976, an array of six short-period vertical seismometers was installed by the EPB around the previously located active region. The data are telemetered to a local site for recording on analogue magnetic tape. Analysis of these data indicates a continuing low level of micro-activity, the events being too small to be seen at the MNQ station ($\Delta \sim 80$ km).

G. Leblanc has continued to advise the Société d'Energie de la Baie James about the need of seismic monitoring in the area of La Grande 2. Difficulties on site have been overcome and on August 4 the monitoring began with a short-period vertical seismograph. The SEBJ has been very thorough in listing all the construction blasts. Up to the end of 1976 no apparent microactivity has been detected.

G.C. Rogers continues to supervise the development of the strong motion seismograph network in western Canada. The present network consists of 32 accelerographs, 61 seismoscopes and 7 peak recording accelerographs, some of which are private instruments under the care of EPB. A magnitude 5.3 earthquake on May 16, 1976 triggered 7 accelero-

graphs and produced low level accelerograms with a maximum recorded acceleration of 0.04 g. 40 seismoscopes also had small amplitude records.

3. Atlantic Geoscience Centre - I Seismology

The Atlantic Geoscience Centre has continued with its ocean bottom seismometer program and has participated in a number of oceanic crustal refraction studies as part of its effort to improve its experimental and theoretical capabilities. As part of the evaluation of different OBS Systems, C.E. Keen and D.L. Barrett undertook a seismic refraction survey on the Mid-Atlantic Ridge at 37°N using the Lamont OBS systems and surface sonobuoys as part of the site survey work for the International Program of Ocean Drilling (IPOD Site 12). The surface sonobuoys showed two well defined layers with velocities of 5.2 and 7.4 km/s. Numerous faults in the crust are evident. Analysis of the OBS data is proceeding although the data were not of high quality. The Centre acquired two OBS constructed by the University of Hawaii which were modified to operate as pop-up units and these were used with two OBS constructed by the University of Washington in a joint project with Earth Physics Branch off the West Coast of Canada. A convenient playback system has been developed as part of the OBS facility to enable easy playback of the data recorded immediately on recovery of the seismometer. The capability of recording relatively high frequencies (up to 300 hz) makes these seismometers very convenient for marine refraction experiments, while still maintaining a capability of monitoring offshore earthquakes.

Atlantic Geoscience Centre - II Physics of the Earth's Interior

The boundary between the Avalon zone and Central Mobile Belt of Newfoundland has been extended northeastward across the continental shelf to the Charlie fracture zone on the basis of geological-geophysical correlations established ashore. The extent of the Avalon zone throughout the Atlantic Provinces has been proposed on geophysical grounds, and the available seismic refraction data appear to support the geochemical evidence for southeastward subduction in Paleozoic time beneath the Avalon Platform.

S.P. Srivastava has been working during 1976 on the synthesis of geophysical data in the Labrador Sea and the development of a model for the evolution of Labrador Sea compatible with this data and that available for the North Atlantic and Norwegian Sea. The results refine previous reconstructions north of the Azores Fracture Zone and indicate that active seafloor spreading started in the Labrador Sea during Campanian (75 m.y.) and continued through to the lower Oligiocene (40 m.y.) when Greenland started to move with the North American plate.

R.K.H. Falconer, H.R. Jackson and C.E. Keen have continued their studies of the continental margin east of Baffin Island. Seismic refraction experiments carried out in 1974 have been interpreted along with gravity and magnetic data in the area. A model of the crustal structure across the transition zone from continent to ocean resulting from this interpretation has been submitted for publication. The model shows a very rapid transition from continent to ocean structure within a distance of 30 km. A deep fault bounded sedimentary basin is delineated immediately landward of the transition zone similar to that found along the western margin of Greenland. Additional refraction data provided information on the velocity and thickness of sediments in the outer Lancaster Sound. A cruise by CSS HUDSON into the Arctic during 1976 enabled additional geophysical data to be obtained in Baffin Bay and along the margins of either side. Additional well controlled magnetic data was obtained in the central Baffin Bay basin to extend the detailed magnetic survey initiated in 1974. Preliminary interpretation confirms the extension of lineated "oceanic" anomalies over significant distances although the trends are somewhat different from those used earlier on the basis of broadly spaced lines.

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

(a) Lithospheric Studies

A refraction seismic crustal survey was conducted in the Beaufort Sea during April and May 1976 in conjunction with the AIDJEX program. The field procedure adopted will allow a structural interpretation and an estimate of the velocity anisotropy of the oceanic crust. Transportation of men and equipment over the broken, mobile ice flows required both a 205-helicopter and a twin Otter to obtain the required number of shots before serious drifting of recording sites occurred.

In October and December 1976, explosions were set off in Charlevoix County and near La Pocatiere, Quebec, by the Earth Structure Section.

The P travel-time data and amplitudes are now being analyzed. Details of the instrumentation used in these experiments are given in section 3 I (c).

R.D. Hyndman has been working in collaboration with D. Barrett of A.G.C. and R.M. Clowes of U.B.C. on the oceanic crustal structure in the Explorer Ridge area. They have completed a very detailed reverse refraction line with explosives, and have obtained deep reflections at ocean bottom seismometers using a large airgun as a source.

R.D. Hyndman, D. Tiffin of the G.S.C. and C.R.B. Lister of the University of Washington have also studied recent faulting near the Explorer Ridge.

G.G.R. Buchbinder and A.J. Wickens have commenced a study of S-wave residuals for the Canadian Network Stations.

C.M. Keith has been working on the dilatancy hypothesis of earthquake occurrence with emphasis on the possible elastic anisotropy involved. The seismological consequences of isotropic and anisotropic dilatant zones are being studied. The effects of anisotropy in the upper mantle on body wave propagation are being investigated, and a paper has been submitted for publication. Some of the effects of a finely layered Moho transition zone have been investigated in conjunction with the study by J.A. Mair and J.A. Lyons of a vibroseis experiment in B.C. (see 1975 Bulletin, p. 32). Some preliminary work on crustal transfer functions in B.C. has been done.

A.J. Wickens has completed a study on the upper mantle of southern British Columbia from the inversion of surface waves. Significant low-velocity zones in the upper mantle were detected in the central and eastern portions of the study region.

M.J. Berry presented a paper summarizing some of the results of EPB seismic refraction and reflection experiments at a symposium on 'The Nature and Physical Properties of the Earth's Crust', held at Vail, Colorado, and sponsored by the U.S. Office of Naval Research.

This paper will be published in the symposium monograph, to be published by the A.G.U. in 1977.

(b) The Whole Earth

G. McMechan completed one study of the effects of crustal structure on the passage of teleseismic body waves, and another on the inversion of low velocity zone structures by considering non-surface focus ray paths. Present investigations include a study of lateral inhomogeneity inversions and a study of water wave arrivals as an aid in interpretation of marine profiles. Also in progress is the determination of upper mantle structure

beneath eastern North America from earthquake data and the SALMON nuclear explosion.

C. Wright and J.A. Lyons have completed a preliminary study of the effects of interference on slowness and azimuth measurements of P arrivals recorded at seismic arrays, which will be published in 1977. The properties of interfering signals have subsequently been used in the development of a method for detecting radial velocity anomalies in the lower mantle. The method has been tested using real data and evidence for triplications associated with velocity anomalies at depths of 1250, 2300 and 2700 km has been obtained. Work is still in progress on the separation of source effects, deep mantle structure and local irregularities beneath the receiver for P wave arrivals at the Yellowknife Array from earthquakes at distances between 40° and 100°. This new approach, using an adaptive processing routine, together with the empirically-derived properties of interfering signals, apparently gives a much higher degree of resolution of the fine details of lower mantle structure than has been possible in earlier studies.

(c) Seismic Sources and Wave Propagation

The EPB continued its work on the seismological detection and discrimination of underground nuclear explosions. During 1976, P.W. Basham assisted the Department of External Affairs at an informal meeting of the Conference of the Committee on Disarmament (CCD) on the Comprehensive Test Ban in April; Basham and D.H. Weichert represented Canada in August at the first meeting of the CCD-sponsored "Ad Hoc Group of scientific experts to consider international co-operative measures to detect and identify seismic events". The Ad Hoc Group will continue meetings during 1977 with plans for a final report to the CCD in 1978.

The CANSAM system at the Yellowknife seismic array continued to operate throughout the year. Small changes were introduced from time to time, to improve the usefulness of the output. Detection bulletins are now airmailed to Sweden and England, and are available on ARPANET.

D.H. Weichert worked one month with the seismic array research group of the German Geological Survey, resulting in an experimental automatic processing and detection system for the GRF broadband seismic array. An evaluation of the potential capabilities of this broadband array for seismic source identification and earth structure investigation is continuing.

(d) Seismological Instrumentation

The instrumentation section has had a busy year with development of the 'Backpack' systems interlaced with an active field program and the on-going maintenance of existing operational systems. A concentrated effort was put into development of the 'Backpack' systems in the early part of the year and one unit was deployed in the AIDJEX experiment in April. Six other 'Backpacks' were kindly loaned by the University of Toronto.

During the summer the section provided support for the cruise on the Endeavor where two Lister-design ocean bottom seismometers were successfully deployed and recovered.

During August the portable array was prepared for one year continuous operation and deployed by helicopter at six sites surrounding the new reservoir at Manic 3. Recording continues through the winter.

In response to concern by local residents a mini-array was constructed and deployed in a salt mine at Windsor. Four vertical components and two

horizontal components are recorded on ½" FM tape (see section 2(a) for further details).

Following the completion of four more EPB 'Backpacks', five units were deployed with six 'smoke' recorders on the north shore of the St. Lawrence for a 1,000 lb. shot on the south shore. From an instrumental point of view the experiment was a success with fifteen components of information recorded, but the results were disappointing from a scientific point due to the high seismic noise level on the day of the shot.

During November the new geotech Triadial long period borehole seismometer was installed at Glen Almond, Quebec. Data from this instrument will be telemetered to Ottawa by a radio link which should be operational by mid 1977.

In December six 'Backpacks' and six 'smoke' recorders were again deployed in the St. Lawrence region and excellent data quality was obtained.

During the year the section has provided in excess of one man year of on the job training to CIDA sponsored technicians from Ghana and Malaysia. The program is continuing into 1977.

The section has also supported the maintenance and calibration of the Canadian Standard Seismograph Network and the routine operation and maintenance of the three computer systems, ECTN, WCTN and CANSAM. In addition a new regional station supplied in 1974 to James Bay Corporation has now been commissioned at LG2, and Atomic Energy of Canada Limited has been supplied with one of the new modular seismographs.

Earth Physics Branch (EMR, Ottawa) - II Physics of the Earth's Interior

(a) Heat Flow and Heat Production

The World Heat Flow Data Collection-1975 has been completed and published. The oceanic data was compiled by J.G. Sclater and M.A. Hobart of M.I.T. and continental data compilation and overall coordination was by A.M. Jessop. The data collection is available in computer-compatible form from the World Data Centre, and in printed form from the Earth Physics Branch. A statistical digest of the data is in preparation. The collection contains 1699 distinct continental values and 3718 oceanic values.

The program to obtain data to delineate the geothermal regime associated with the tectonically active Pacific rim was continued. R.D. Hyndman and T.J. Lewis measured heat flow in the Winona Basin off Vancouver Island, and T.J. Lewis and A.S. Judge obtained more heat flow sites in southern British Columbia and in the Yukon.

T.J. Lewis has analysed over 220 samples of rock for uranium, thorium and potassium content using a gamma-ray spectrometer with a solid state detector. Most of the samples came from the Cordillera in both the Yukon and British Columbia. Some of these samples are associated with heat flow measurements, some with rocks that have been age-dated, and some represent large surface exposures.

R.D. Hyndman, with C.R.B. Lister and S. Wade of the University of Washington, and E.E. Davis of M.I.T. also obtained heat flow data off the west coast. Very closely spaced measurements with a pogostick type telemetry probe outlined hydrothermal cells in the oceanic crust and at least one hydrothermal vent with associated deposits of possible economic importance.

R.D. Hyndman has also made detailed heat flow measurements in Saanich Inlet and Nitinat Lake, southern Vancouver Island, to outline the low heat flow zone produced by the subduction process. Hyndman has also prepared a report in collaboration with A. Erickson of the University of Georgia on "Heat Flow in D.S.D.P. Leg 48 Holes".

(b) Permafrost Studies

A.S. Judge and A.E. Taylor have now published a total of 78 permafrost thickness determinations based on deep temperature measurements in northern drillholes. A further 8 new determinations were made in the Mackenzie Delta this year bringing to 33 the number of sites in that area. In general, permafrost thickness is highly variable regionally, ranging from 65 m to greater than 600 m in the onshore Mackenzie Delta. As an aid in the interpretation of these subsurface temperature analyses, A.E. Taylor has developed a numerical model to determine the physical parameters of the surrounding formation, such as ice content, porosity, pore-water salinity and lithology.

The only other naturally occurring crystal structure of ice is a gas hydrate. A.S. Judge, together with M.K. El-Defrawy of D.I.N.A. and D. Davidson of N.R.C., is investigating their distribution in northern Canada with a current emphasis on prediction and detection. Combined seismic and thermal studies of the permafrost and hydrates beneath the offshore areas of the Beaufort Sea by A.S. Judge and J.H. Hunter of the G.S.C. have continued to map a distribution pattern which relates closely to the combined history of water and ice cover. The high cost of conventional drilling in the area has led to the joint development with J.A. Hunter of G.S.C. of a hydraulic jet-drill. Shallow thermal studies of the near-surface regime have been continued by M. Burgess in conjunction with the Beaufort Delta Oil Project in the Beaufort Sea, and have been recommenced by A.S. Judge and J. Collier in the Arctic channels using mud temperature gradiometers originally developed to measure terrestrial heat flow through the ocean floor. These studies, together with studies by A.S. Judge and J. Collier of the permafrost distribution of Arctic shorelines in the vicinity of Byan Martin and Little Cornwallis and measurements of ground temperatures in eastern Melville, have been in support of Arctic pipeline appraisal. For similar purposes routine measurements of the thermal properties of frozen and unfrozen soils and rocks have continued. All the available data on such materials have been collected by P. Purushothamaraj, and are being analysed in the hope of finding universal models connecting thermal and other physical properties.

(c) Geothermal Energy

The Federal Government's efforts in research into Canada's geothermal resources increased significantly during 1976. For the first time, funds were available for contract work directed towards geothermal energy. Overall coordination was by A.M. Jessop, and individual contracts have been managed by J.G. Souther of the G.S.C. Vancouver, L.K. Law of the EPB Victoria, and A.M. Jessop.

In the volcanic regions of the western cordillera five projects were undertaken, four of which were centered on the Meager Mountain area of the Garibaldi Volcanic Belt. Geological mapping to a scale of 1:25,000 of the Meager Mountain volcanic complex, and a detailed geochemical study of the Meager Creek drainage system were undertaken. A small scale magnetotelluric experiment in the main Lillooet Valley, downstream from the junction of Meager Creek, was completed. Various volcanic centres in the Garibaldi Belt have been examined by age-dating techniques. All of these projects were designed to improve our knowledge of the age and structure of the volcanic centre in order to yield indications of the magnitude and location of geothermal resources. A reconnaissance

geochemical survey of hot springs in the Yukon was also undertaken, since this area had not previously been covered. Reports of all five projects should be completed during the winter.

A preliminary study of the hot water potential of the western sedimentary basin has been completed and phase two of the study is beginning. In phase one the data collection of the Geothermal Survey of North America was examined, and indications of reservoir temperature, thickness and other characteristics were indicated. Phase one dealt with wide areas of the Prairies, but Phase two is designed to focus on three specific areas that have been selected to give a range of geological conditions and human surface habitation patterns. The main conclusion so far is that there is a very large amount of heat stored in hot water in sedimentary formations, and since the water is at temperatures up to 175°C, the best use is for space heating. Economic factors and practical difficulties of production and location have not yet been examined. Contract work was done by Sproule Associates Ltd.

(d) Tectonophysics

R.D. Hyndman and R.P. Riddihough have reviewed data indicating subduction under southwestern B.C. to provide a framework for other studies in the same area. This review is the first part of a more detailed study of the region that will include thermal and gravity models and an examination of the reasons for the absence of a deep Benioff zone.

R.D. Hyndman, in collaboration with N.I. Christensen of the University of Washington, has examined the physical properties of basaltic rocks from boreholes in Bermuda and the Azores. Extensive laboratory measurements of seismic velocity, density, porosity, electrical resistivity and thermal conductivity are being compared with the relevant field data.

C. Wright is investigating methods that might be developed or are already in use for determining the stress field and stress changes within the crust. Possible relationships between the composition, physical properties and state of stress of the lithosphere are also being studied.

5. University of Alberta - I Seismology

(a) Theoretical Studies

Dr. M. Razavy and M. Hron have found a solution of the direct and inverse problem for a system of one-dimensional difference equations using J-fractions. The solution is exact and unique and is applicable to the propagation of acoustic waves. The method was tested by comparing its results with the analytic solutions of a one-dimensional differential wave equation. The agreement of both solutions is remarkably good.

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

curves are then mapped in the $\tau(p)$ plane. The TAU method has been applied to Early Rise data recorded by various research laboratories to obtain velocity models showing lateral variations. The role of the interpreter is less critical in biasing the models so obtained. Low velocity layers may be incorporated in the inversion process.

Mr. Claude Athias and Dr. E.R. Kanasewich are investigating the perturbations to a seismic recording due to a reef-like mixed boundary conditions.

G. Churney, Mr. D. Ganley and Dr. E.R. Kanasewich are making a study of synthetic seismograms for reflection studies in which attenuation is being examined. Mr. K. Sprenke and Dr. E.R. Kanasewich have completed a study of teleseismic synthetic seismograms in which the medium is both anisotropic and attenuating. The Haskell-Thomson matrix formulation was modified to yield synthetic seismograms and theoretical spectral ratios in a system of parallel anisotropic lossy layers. Transfer function matrices were derived for the case of transverse isotropy with a vertical unique axis. Short period spectral ratios and time syntheses are found to be significantly affected by the presence of uniaxial anisotropy for a typical continental crustal model while long period spectral ratios are shown to be sensitive to anisotropy in the upper mantle. Synthetic seismograms for a continental crust indicate that crustal reverberations of teleseismic impulses are attenuated within 5 seconds of onset. This suggests that the duration of observed P codas which typically last 20 seconds or even much longer for larger earthquakes is not due to crustal effects.

L. Marks and Dr. F. Hron have developed an alternative high frequency method replacing asymptotic ray theory in the vicinities of critical points where the latter is invalid. The new method which expresses the ray amplitude in terms of parabolic cylinder functions has been incorporated into existing programs and sets of synthetic seismograms for various layered models have been produced. The dominant role of multiple converted head waves within the first seconds of seismograms has been proved and linked to the strong groups of dynamic analogs containing sometimes more than 100 individual waves.

A similar program designed for the computation of synthetic seismograms for anisotropic layers has been developed by P. Daley and Dr. F. Hron. They will be investigating the difference in the seismic response for anisotropic media and stacks of homogeneous isotropic parallel layers.

A. Choi and Dr. F. Hron have initiated the studies leading to the selection of the most favourable ray method which would be used in the new program computing synthetic seismograms for a radially inhomogeneous spherical Earth.

With the rapid development of seismic numerical modelling, demand for the studies related to the seismic wave propagation through more realistic media has increased tremendously.

Dynamic properties of seismic body waves propagating through anisotropic media have been investigated by P. Daley and Dr. F. Hron. Asymptotic ray theory has been used for the computation of amplitude-distance characteristics and for the derivation of reflection, transmission and head wave coefficients. Influence of anisotropy on the coefficients has been studied numerically in the case of elliptical anisotropy.

Theoretical study of the properties of seismic waves in anelastic media has been initiated by E. Krebes and Dr. F. Hron. Non-linear wave

theory will be used in the attempt to compute dynamic characteristics of seismic body waves.

(b) Experimental Seismology

Dr. E. Nyland and Mr. D. Au extended a computer automated system for extracting travel time information from the data tapes of the International Seismological Centre which was devised with Mr. E.J. Roebroek. Travel times can be analyzed for delays in various three dimensional volumes of the earth. The technique has been applied in the lower mantle to investigate possible lateral variations of velocity at the core-mantle interface. Anomalies exist but they cannot be unambiguously assigned to the lower mantle.

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

Dr. L. Malinovskaya of Moscow is studying differences between seismograms from events near large lakes and further from these lakes.

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

A study of optimum array design using backward error analysis of wave slowness has been made by A.C. Bates and Dr. E.R. Kanasewich. Arrival times of plane waves at stations of a two dimensional seismic array may be inverted to obtain the slowness and azimuth of plane waves. It has been found that the stability of the inversion process is related to the condition number of the matrix inversion and that symmetric arrays yield the most stable estimates of slowness and azimuth in the presence of travel-time errors. If travel-time errors are given in the root mean square error sense then the least square error inversion results in maximum and most likely error ellipses in the slowness-azimuth error plane for any array. If travel-time errors are bounded then errors in the slowness-azimuth error plane are bounded by multisided figures which reflect the array configuration. Several array configurations are used to illustrate that the most effective procedure for error improvement is to add additional stations along the periphery of an existing array instead of in the interior.

(c) Instrumentation

Seismic Event Monitor. Development and construction of 20 seismic systems is being carried out by Dr. E.R. Kanasewich, Mr. M.D. Burke and Mr. L. Ramsdell. This digital system will record on magnetic tape a short section of events detected by a vertical Mark Product L-4 seismometer and the corresponding WWVB time signal. The systems are being designed to operate on low power from a battery supply in remote locations for periods of several weeks. A microprocessor is being used to detect events and control the system.

A radio telemetry system including controls by a TI 990 mini-computer is being built to update the variable aperture seismic array.

The data link from the observatory to the Physics Department has been upgraded with an extension of the memory on the PDP-11 from 12,000 words to 28,000 words.

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

(a) Geodynamics

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

Dr. E.R. Kanasewich, Mr. Jens Havskov and Dr. M.E. Evans have made a study of the symmetry of the continental lithosphere during Tertiary, Cretaceous, Triassic, Carboniferous, Devonian and Cambrian periods. A new reconstruction of the continental margins was made using paleomagnetic observations. The symmetry is observed under suitable rotation of the data using one of several well known map projections (Azimuthal equidistant, Eckart, etc.). Initial results indicate that the continents and hence the major plates of lithospere were as highly organized in the past as at the present (Kanasewich, 1976) in one of two patterns.

The Peruvian microgeodetic network operated by Dr. E. Nyland in cooperation with colleagues from the University of New Brunswick has been remeasured. Only very small changes appeared in 9 months. A computer program has been developed to invert these changes to creep mechanism characteristics. An experimental creep meter has been installed and will be supervised by Ing. Ernesto Deza of Peru. Reconnaissance is complete for a network at Ica on the coastal plain of Peru.

(b) Earth Tides

With Dr. J. Rogers of the Low Temperature group in the Department of Physics, Dr. Jones and Mr. Park are constructing a Stacey-type mercury tiltmeter to be used for measuring earth tides and local tilts. A test cell has been constructed and tested and this has led to modification of the Stacey design to enable better control of the mercury surface. Programs have been acquired from Dr. C. Beaumont of the Earth Physics Branch, Ottawa, and these have been adapted for use on the University of Alberta computer. Also, data have been obtained from Professor P. Melchior from one station in Belgium and these will be analyzed at Alberta. It is intended that a number of tiltmeters will be built and measurements conducted in the Rocky Mountains and Great Plains of Alberta.

6. University of British Columbia - I Seismology

S. Knize and R.M. Clowes have completed interpretation of deep seismic sounding (DSS) data acquired in 1973. DSS profiles about 20 km in length were recorded in three regions: the Hudson '70 survey area near 51°N, 133°W; off Queen Charlotte Sound; and in Cascadia Basin west of central Vancouver Island. After compilation in record sections, the data were interpreted: for the refraction data, models are based on a traveltime and amplitude interpretation with the aid of synthetic seismograms; for the reflection data, they are based on a $T^2 - X^2$ anaysis of correlated seismic phases. Excellent agreement of models from the two approaches was achieved. The model for the region off Queen Charlotte Sound indicates six sedimentary layers of different velocities, basement at a depth of 2.4 km sub-bottom, and the oceanic layer at a depth of 4.5 km sub-bottom. Velocity reversals within the sediments possibly show the influence of Pleistocene glaciation on sediment deposition. The model for Cascadia Basin shows four layers within the sediments of thickness 1.9 km, a velocity transition between the sediments and the basement at a depth of 2.7 km sub-bottom, and the oceanic layer at a depth of 4.2 km sub-bottom. Proposed interbedding of volcanic material with high

velocity sediments at the top of the basement correlates with geological formative processes observed at the crest of the nearby Juan de Fuca Ridge.

S.J. Malecek and R.M. Clowes have completed interpretation of the data set acquired in 1974. Two reversed 75 km DSS profiles were recorded in the Explorer Ridge region of the NE Pacific, one parallel and the other perpendicular to the ridge. Seismograms recorded at distances beyond 4 km were stacked, filtered, statics and amplitude-corrected before compilation as record sections. The data have been interpreted using both traveltime analysis and amplitude studies with the aid of synthetic seismograms. The profile run across the ridge showed no anomalous behaviour as the ridge was crossed; the profile on the Juan de Fuca plate, paralleling the ridge, exhibited traveltime branch offsets and delays. These have been interpreted as due to faulting with vertical offsets of about 5 km. Velocity gradients within the crustal layers are required. "Layer 2" consists of two layers with a total thickness between 2 and 3 km; "layer 3" has a thickness between 6 and 7 km. Thus the total sub-bottom thickness of the oceanic crust varies between 8 and 10 km except in the faulted region. This anomalously thick crust near a ridge is possibly due to recent deformation of Juan de Fuca plate. The reversed upper mantle velocities are 7.8 and 7.3 km/s in directions perpendicular and parallel to the ridge. Anisotropy is proposed to explain these different velocities.

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

S. Lynch and R.M. Clowes are proceeding with analysis of the 90 km profile recorded along the length of the basin. The numerous digital data have been edited, demultiplexed and timed. Reduced traveltime curves of first arrival refraction data for distances from 8 km have been interpreted by the slope-intercept method for reversed data. The preliminary results give about 3 km of sediment with an assumed velocity of 2.8 km/s. Beneath the sediments, there are a series of layers with velocities of 4.3, 5.3, 6.4 and 7.1 km/s and approximate thicknesses of 1.3, 3.0, 4.0 and 4.0 km, respectively. Slight dips on some horizons are obtained. The unreversed velocity for the top of the upper mantle is 7.8 km/s. These results indicate a possible "transition-type" crust with a total sub-bottom thickness in excess of 15 km. A traveltime and amplitude interpretation of the refraction record sections and analysis of the reflection data are in progress.

R.M. Clowes and S. Lynch co-operated on a marine research cruise, during August 1976 with Chief Scientist Dr. R.D. Hyndman of the Victoria Geophysical Observatory, Earth Physics Branch. The specific aspect of their contribution involved a detailed reversed seismic refraction profile using ocean bottom seismometers (OBS) of Earth Physics Branch, Victoria and the Atlantic Geoscience Centre, Dartmouth. The 4 instruments were deployed in a line perpendicular to and north of the Explorer spreading centre at distances of approximately #1 - 0, #2 - 30, #3 - 70 and #4 - 74 km. The last two were very close in an attempt to obtain array apparent velocity by phase correlation. Number 4, one of the A.G.C. instruments, did not return to the surface at the preset time and was lost. The others recorded satisfactorily. 5000 lbs of explosives were shot along the line in alternating large (up to 400 lbs) and small shots; then the 1000 cu. in. airgun was fired along the line and on cross lines at 2 minute shot intervals. Simultaneous recording on a CSP system was done also. The explosives were well recorded the length of the line; even the airgun was recorded, although weakly, to over 50 km. The

experiment should provide an excellent reversed refraction line 70 km long with a good chance of shear wave information.

Seismic activity associated with the filling of McNaughton Lake (Mica) has been continued by R.M. Ellis and H. Dragert using a telemetered seismic array. Loading was initiated in March 1973 with full load of 25×10^9 m^3 and maximum depth 191 m reached for the first time in July 1976. An earthquake swarm of 747 events ($M_L > 0$) with largest event $M_L = 4.7$ occurred within 17 km of the reservoir just prior to loading. Subsequent to this, three swarms of 194, 292 and 22 events with maximum $M_L = 4.1$ occurred in the same region; however, no earthquakes have occurred between the reservoir and the swarm area. The level of regional seismic activity is similar to that observed prior to loading. The distribution of this activity, excluding swarm events, exhibits a spatial pattern similar to that recorded earlier by regional seismic stations, except that several events appear to be associated with the fault underlying the Rocky Mountain Trench in which the lake is formed. During a loading-unloading cycle in which the maximum water depth varied from 98 m to 171 m to 131 m, the change of v_p was less than 2%. This indicates that no significant change in dilatancy or degree of water saturation occurred in the upper crustal layer during this cycle. Observations will continue to at least the summer of 1977.

Observations on a new reversed refraction profile across the Rocky Mountain Trench have been initiated by R.M. Ellis using as seismic sources Cominco's Sullivan Mine on the west wall of the Trench and Kaiser's Sparwood operation 80 km to the east. Recordings are being made at 5 km intervals from the Sullivan Mine to the east wall of the Trench and as densely as access permits further east.

J.C. Davies and T.J. Ulrych have applied the MEM technique to the analysis of the UCLA Gravimeter recording of the 1964 Alaskan earthquake. Time adaptive MEM and AR modelling were used to identify and correct glitches in the data set. This procedure considerably increased the signal to noise ratio at the low frequency end of the spectrum. The enhanced record was analysed for the existence of possible core undertones. Although no evidence of core modes was found, a number of unexpected peaks did appear in the frequency range 0.125 - 0.725 cycles/hour.

L.R. Lines and T.J. Ulrych have completed a comprehensive review of single and multichannel, linear and non-linear deconvolution methods. The investigation includes the analysis of methods of wavelet estimation and the application of a time adaptive MEM approach to non-stationary problems.

W.B. Cumming, R.M. Clowes and R.M. Ellis are continuing with analysis of a partially reversed seismic refraction profile which was recorded across southern British Columbia during the summers of 1973-75. The forward profile, directed westward from the blast site at Kaiser Resources open-pit coal mine near Sparwood, B.C., consists of 38 three-component, short period seismograms recorded at distances from about 6 km to 400 km. Station spacings are typically between 10 and 15 km. The reversed profile is directed eastward from two blast sites, about 2.5 km apart, in the Highland Valley. It consists of 44 seismograms recorded at distances from about 5 km to 300 km, with station spacings varying from less than 5 km to about 15 km. Precise blast locations have been made through the co-operation of the mining companies. Origin times for most blasts have been determined by using a shot point system at the mine site. In some cases, remote timing by the Mica seismic array was necessary. The numerous seismic data, which were recorded on FM analog magnetic tape, have been edited and digitized to facilitate subsequent analysis. Amplitude corrections have been made so that the final record sections are representative of the true signal amplitude variations. Exceptional geotectonic variations occur along the profile and these are evident in a qualitative sense on the record sections. Interpretation, which is currently in progress, will use the traveltime information and the general

amplitude trends. As well, a delay-time procedure is being applied to the data to provide information about the crustal structure near the shot sites and possible variations of topography on the M-discontinuity.

G.D. Spence, R.M. Clowes and R.M. Ellis have completed additional geophysical studies in the southern Rocky Mountain Trench. From a P-wave interpretation of a seismic refraction survey in the Trench, Bennett et al. (1975) (see Publications) suggested a high-angle crustal fault crossing the trench near Radium as one of three possible explanations for their data. To test this hypothesis, a gravity survey has been carried out in and adjacent to the trench in the Radium area. The resultant data are not consistent with the proposed fault model. The principal feature of the data is a pronounced low which coincides with the trench throughout the survey area and is best modelled by Cenozoic fill to a depth of about 500 m. To provide additional information, shear-wave arrivals recorded during the seismic survey have been enhanced by polarization filters. These S-wave data are not adequate quality to provide an independent interpretation, but they show consistent behaviour with the P-wave data. The calculated S-wave velocities are low, implying a high value of Poisson's ratio. To determine maximum and minimum depth limits to the Moho allowed by the seismic data, an extremal analysis was performed on both the P and S wave record sections. From the P-wave data, the limits on crustal thickness beneath the trench are 52 and 60 km; from the S-wave data, the limits are 47 and 59 km. As a result of these additional studies, the two alternative hypotheses to explain the seismic data must be reconsidered. These are (1) the existence of a crustal low velocity zone and (2) a major deformation of the basement and overlying rocks due to the trench being an ancient zone of weakness which coincides with the western limit of the continental Precambrian craton. As reflections from the boundaries of the low velocity zone are not observed by Bennett et al., the second alternative is preferred.

W. Moon and R.A. Wiggins have completed the development of a variational type, finite element method for the study of normal modes of a rotating, laterally heterogeneous Earth. This method is very powerful and, in theory, overcomes all the limitations of the perturbation method. However, the present size of computer memory puts severe limitations on the use of this method. The Lagrangian energy integral is derived for a general configuration of a perfectly elastic continuum in both spherical and oblate ellipsoidal co-ordinate systems. The assumed solutions for the displacements and the perturbation of the gravitational potential are formed by tensor products of the cubic Hermite basis functions of three co-ordinate variables. The undetermined coefficients of these assumed solutions are solved by the minimizations of the Lagrangian energy integral by a Rayleigh-Ritz technique. The results of the numerical solution of this approach show that (1) this algorithm is very efficient and promising in one-dimensionalized normal mode problems, (2) that the degenerate frequency of ${}_nW^{m\ell}$ splits into $(2\ell + 1)$ components, even for the non-rotating, homogeneous spherical Earth model, due to the interpolation scheme of the azimuthal basis functions and (3) because the numerical spectral splitting is very large, the effects of self-gravitation and rotation cannot be examined clearly in this study. However, lateral heterogeneities which break the symmetry of the physical shape of the Earth greatly affect the normal mode spectra.

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

Recent research has indicated that thermal convection is the only type of motion likely to be energetic enough to drive the geomagnetic dynamo. However, both the nature of convective motion and the energy constraints depend on the physical properties of the material in the outer core.

J.M. Gilliland has used a combination of thermodynamic arguments and the theory of liquid metals to determine the adiabatic temperature curve in the core in a self-consistent way from available seismic data and estimates of the

temperature at the boundary of the inner core. It is found that the adiabatic temperature varies linearly with molar volume to a close approximation, for a wide range of inner-core boundary temperatures, with the core-mantle boundary temperature being approximately 0.83 times the inner-core boundary temperature. The argument makes it possible to determine the volume and temperature dependence of the Gruneisen parameter, the thermal expansion coefficient, and the specific heat in the outer core. An extension of the argument allows the electrical and thermal conductivities to be determined. The electrical conductivity is found to increase by a factor of 1.5 from the core-mantle boundary to the inner-core boundary, while the thermal conductivity increases by a factor of about 2. The thermal expansion coefficient decreases by a factor of 1.6 and the Gruneisen parameter decreases by a factor of about 1.2 in the same interval. The heat flux from an adiabatic core is found to lie in the range 5.5 - 7 x 10^{12} watts.

J.M. Gilliland has also obtained estimates of the inner-core boundary temperature from a study of the pressure and volume dependence of the melting temperature of iron at core pressures. Both the Kraut-Kennedy and the Ross-Lindemann melting laws are inadequate approximations in this range. An intermediate form of the melting law has been determined from thermodynamic arguments. The phase relations of iron have also been studied, in conjunction with the seismic evidence. It appears likely that the gamma-epsilon-liquid triple point of iron occurs at core pressures, rather than at lower pressures as has been suggested by other workers. The most likely range of inner-core boundary temperature, on this assumption, appears to be 4800 - 5500°K.

J.M. Gilliland has studied the relationship of the time variation of the dipole component of the geomagnetic field to processes near the core-mantle boundary. It appears that the effect of precession of the Earth on motions in the core, while insufficient to drive the dynamo, may well give rise to geomagnetic reversals.

7. Dalhousie University - I Physics of the Earth's Interior

Cooperative studies between the Atlantic Geoscience Centre and the Department of Geology and Oceanography, Dalhousie, are being carried out by C.E. Keen, M.J. Keen, B. Hall and K. Sullivan. These are centered on the Newfoundland Basin. Studies are being conducted on the sediment thickness and crustal properties in the Newfoundland Basin, using data obtained with expendable sonobuoys and single-channel reflection systems. On the cruise of MARTIN KARSLEN in October 1976, one complete reflection profile was obtained from east-to-west south of the Newfoundland Seamounts, from magnetic anomalies 31-32 to the J(/) anomaly just seaward of the continental margin.

8. University of Manitoba - I Seismology

D.H. Hall has interpreted sub-Moho velocity discontinuities beneath the Superior province of the Canadian Shield in terms of a pyrolite model for the mantle. This model would suggest spinel to garnet transitions and partial melting to be present in the lithosphere in this area.

A seismic reflection survey was conducted by O.G. Stephenson in the Mafeking-Dawson; Bay area of Manitoba under contract to the Mines Branch, Department of Mines, Resources and Environmental Management. The purpose was to determine the structure of the Paleozoic sediments, in particular, the reefal build-up in the Devonian strata. Six-fold coverage was obtained using a Dinoseis source and a 24-channel analog recording system. Coverage was along two lines with a total length of approximately 25 and 8 kilometers respectively. Time and depth sections were produced.

O.G. Stephenson and D.H. Hall are completing the interpretation of a seismic refraction survey which was conducted along the Provincial Highway from Thomson to Lynn Lake, Manitoba.

D.H. Hall, O.G. Stephenson and A.G. Green are carrying out a coverage with single trace recorders placed at points on a 60 km grid intended to cover the north-west corner of Manitoba north of Lynn Lake. In 1976 recordings were obtained at 8 of the grid points from 2 shots of 950 lbs. weight. Interpretation is in progress.

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

E.R. Deutsch and R.R. Patzold have made studies of samples from the Nazca plate.

Measurements of magnetic and thermomagnetic properties of basalt from leg 34 of the Deep-Sea Drilling Project indicate that our 46 samples contained stable single-domain (SD) or pseudo-SD magnetite or titanomagnetite. The mean inclination after af and thermal demagnetization is $\bar{I} = -15^{o}$, close to the present dipole field, at site 321 but is anomalous ($\bar{I} = +53^{o}$) at site 319. In 31 samples of massive basalt from both sites the stable remanence at 20°C was masked by a low-coercivity component. High-field hysteresis loops are narrow at 20°C and broad below the -155°C magnetite transition. These samples, which we denote type 1, exhibited wide or constricted Rayleigh loops in 10 Oe. Although the magnetite in type 1 samples tends to be coarse ($> 100\ \mu m$), our findings demonstrate that the effective source of type 1 magnetite properties is not multidomain structures but fine predominantly superparamagnetic interacting particles that become stable SD at low temperatures. The other 15 samples (type 2), containing finer-grained magnetite or titanomagnetite, were stable at 20°C, did not show Rayleigh loops, and produced highly irreversible thermomagnetic curves consistent with SD behaviour and oxidation upon heating. Between 20° and 105°C all type 1 k-T curves rose spectacularly towards a Hopkinson-type peak, while the natural remanence and the Koenigsberger ratios (~1-10 at 20°) decreased sharply. Therefore in areas underlain by such rocks, magnetic anomalies must be interpreted with care.

10. University of Saskatchewan - I Seismology

D. Gendzwill and Z. Hajnal are testing our seismic recording system which consists of six L-4 seismometers (Mark Products), an analogue to digital converter, a Texas Instruments 980 A minicomputer and a Cipher digital tape recorder. The system should be operational soon and is intended to record local seismic activity in Saskatchewan.

11. University of Toronto - I Seismology

J. Wright has completed, for his Ph.D., an interpretation of seismic refraction-reflection surveys that he carried out in the southern part of the Geotraverse in 1973, 74. No evidence of major "topographic" structure in the crustal layering was found, but the boundaries under the southern part are shown to be more gradational than in the central area. Vertical and radial component seismograms were recorded along two 215 km profiles and two short profiles northwest of Lake Superior in the Canadian Shield. The northern long profile runs NNE from Atikokan past Sturgeon Lake and was recorded in one direction only using open pit mine blasts as the source. The southern long profile runs SSE from Atikokan to Lake Superior and was recorded from three widely separated shot points along the line using explosives in old abandoned shallow mine shafts and from the open pit mine blasts at Atikokan. Geologically, the survey area is typical Archaean gneissic and granitic/greenstone terrain. However, two distinct velocity depth models were derived from the two major profiles.

Upper crustal P wave velocities vary between 5.93 and 6.31 km per second. High velocities (greater than 6.5 km per second) were found in the lower crust throughout the area. A shallow low-velocity zone may be present in the south. In the northwest, a fairly sharp (Conrad) discontinuity divides the

crust into two layers. A distinct M discontinuity lies at the depth of 40 - 44 km. However, in the southeast, no sharp discontinuities are found within or at the base of the crust although gradational zones exist which can be correlated with the sharper discontinuities in the N.W. The pronounced difference between the two adjacent areas may be due to the proximity of the anomalous Lake Superior crustal region to the southern profile.

At present, the composition of the lower crust and the nature of Archaean tectonic processes are uncertain. However, the physical properties of anorthosite are compatible with the inferred properties of the lower crust. A tectonic scheme for the emplacement of anorthosite is described.

G. West and R. Young continued the seismic surveys in 1975 using a variety of mine blasts as sources. A series of record sections have now been compiled and are being interpreted. Recording was concentrated in the Wabigoon and English River subprovinces along Hwy. 599, with sources in the Mesabi range (Δ = 210-330 km), at Atikokan (Δ = 75-219 km), at Red Lake (Δ = 184-200 km) and near Sturgeon Lake (Δ = 12-80 km). This is expected to give a much more detailed picture of velocity structure in the central Geotraverse area than could be obtained from Wright's data. The P_n first arrival data from the Mesabi range give an excellent linear fit to $T = (7.81 \pm 0.1 + \Delta/8.31 \pm .03)$ sec. indicating no rapid lateral variation in the velocity structure of the crust. However, the short range data show average velocity variations between 6.1 and 6.7 km/s for paths through widely differing geology (predominantly granitic-predominantly greenstone).

M. Godlewski has studied earthquake surface-wave propagation along a line from Flin-Flon to Thunder Bay crossing the Geotraverse. The study was made of the dispersion of fundamental Rayleigh mode surface waves along a line in the Superior Province of the Canadian Shield, from Flin Flon, Manitoba to Thunder Bay, Ontario (a distance of 1121 km). The two station method together with multiple filter analysis was used to determine the interstation group velocities of surface waves from 5 Alaskan earthquakes. The observed dispersion was then inverted to obtain the average shear velocity as a function of depth. The data are found to indicate a typical shield velocity structure and a crustal thickness of 40 $\pm$ 3 km. The average shear velocity of the upper crust is found to be 3.55 $\pm$ .08 km/sec, and the lower crust is found to have a velocity of 3.95 $\pm$ .05 km/sec. The data also indicate an average upper mantle shear velocity of 4.60 $\pm$ .15 km/sec and suggests the presence of a slight (4.55 km/sec) low velocity zone.

The results agree well with body wave seismic studies conducted in the same area and when these observations are combined with the results of this study they yield an interestingly high Poisson's ratio (.275 $\pm$ .007) for the lower crust.

A compilation by D.R. Hutchinson, H.C. Halls (U. of T.) and P.W. Pomeroy (N.Y. State Geological Survey) of historic and recent seismic activity in western New York state shows an association of epicentres with portions of the north-south trending Clarendon-Linden fault structure. This research project involved a marine seismic profiling investigation of the Lake Ontario bottom sediments to search for the northward continuation of the fault across the lake.

Two high resolution seismic systems (7 kHz and Uniboom), a 1 in 3 (compressed air) Airgun and a proton magnetometer were used to collect over 400 km of data in April 1976.

The data will be used with the Canada Center for Inland Water's core data and the Geological Survey of Canada seismic data to compile a seismic stratigraphy for the lake, an inferred Quarternary history of the lake, and an analysis of the suspected fault structure.

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

G. West has argued that due to the higher heat generating capacity of rocks in Archaean time that crustal rocks might soften very significantly if covered by substantial thickness of volcanics. If sufficient softening occurred, the denser volcanic pile would tend to sink into the substream and part of the substratum would push up through the volcanics. J.C. Mareschal has computed one-dimensional heat flow models to determine quantitatively what amounts of U, Th, K would be necessary to permit such a process to begin. A paper on the subject demonstrating the general feasibility of the mechanism was presented in the 1976 Geotraverse Workshop. Subsequently, Mareschal has been constructing a two-dimensional finite element model of slow-viscous flow and thermal transport where the viscous parameters are temperature dependent. This work has reached the point where preliminary test cases have been run and the thermal part of the problem has been verified. We hope that the whole modelling program will be operational early in the New Year and we can then begin to study a variety of geological models.

Six measurements of heat flow have been made by R.G. Allis in the sediments of thermally stable lakes in the geotraverse region of northwestern Ontario. Each heat flow is the average of measurements made during May and September 1976, from 3 to 6 neighbouring lakes. The local heat flow from each lake has been corrected for the effects of the immediate thermal history, lateral temperature contrasts, sedimentation, and refraction. A correction for climatic variations during the Pleistocene has also been calculated. This was based on a glaciation chronology determined from oxygen isotope variations in deep sea cores. The magnitude of the correction suggests that the surface heat flow throughout most of northwestern Ontario is depressed by about 20% at present. In situ measurements of heat productivity at each location were measured with a portable gamma ray scintillation counter.

The heat flow-heat productivity data are generally consistent with the linear relationship found from other measurements in the Superior Province and the eastern and central U.S. They confirm previous suggestions that this area of North America is a single heat flow province characteristic of stable continental crust.

A correlation between the Bouguer gravity anomaly and heat flow has been found for the Superior Province. The slope of the regression has been found for the Superior Province. The slope of the regression line ($1 mW m^{-3} = -4$ mgals) is that which would be expected from the relationship between heat productivity and density of common crustal igneous and metamorphic rocks. Using this relationship and an empirical relationship between density and seismic P-wave velocity, a model has been developed for the variation of heat productivity with depth in the crust. It satisfies the constraints from P-wave velocity profiles in the crust, surface heat flow and differential erosion, and the mean density of continental crust. The model implies that lateral variations in surface heat productivity decay exponentially with depth to a mean heat productivity of about 0.9 $\mu W m^{-3}$ at the base of the upper crust. The lower crust would be relatively depleted in the heat producing elements.

12. University of Western Ontario - I Seismology

(a) Theoretical Studies

The spheroidal and toroidal fields, in a rotating elliptical earth with a fluid outer core, are coupled. These fields have been studied by P.Y. Shen and L. Mansinha. The coupling chain is infinite and must be truncated for any numerical solution. Two types of core oscillations have been investigated. "Core undertones" are characterized by comparable spheroidal and toroidal components and a frequency spectrum depending strongly on the density stratification of the outer core. No quantitative

results have been obtained for this mode. A proper truncation scheme has yet to be found.

The "toroidal core oscillations" are characterized by a large primary toroidal field accompanied by a small secondary field. The eigen frequencies are determined by the ellipticities of the two outer core boundaries. Elasticity and self-gravitation of the earth have only a small effect. Owing to the nature of this type of free core mode, the coupling chain can be truncated. Numerical results correct to this first order in ellipticity have been obtained.

During the past year a series of numerical experiments were performed by R.F. Mereu with the aim of studying the properties of a new deconvolution filter which is optimum in the "error-distribution" sense. By increasing the number of sub-filters used in the design, one can control the errors and move them away from the region of interest leaving that region effectively "error-free". This filter differs in principle from the Wiener filter which is optimum in the least squares sense. Theoretically the new filter is composed of 3 components, i.e. a symmetric component, a component which depends on the basic wavelet and a component which depends on the desired wavelet. Tests showed that if the symmetric component is derived from a linear combination of the autocorrelation function of the basic wavelet and the autocorrelation of the noise, a very effective filter results which is capable of simultaneously contracting the wavelet and reducing the noise. Other tests showed that the length of a significant portion of the filter depends very much on whether or not the z transform has a zero on or near the unit circle.

(b) Experimental Studies

The feasibility of delineating non-layered anomalous velocity zones by means of a modified form of fan shooting and least squares analysis is being examined by C.E. Wahoso and R.F. Mereu. The least squares analysis is similar to that introduced by Aki et al. (1975) for the statistical analysis of P-wave amplitude and travel time anomalies observed over the NORSAR and LASA arrays.

Synthetic model tests have been carried out on the computer and a field experiment was carried out in July of this year on the Gertrude West massive sulfide deposit (owned by INCO Ltd.) in Sudbury. The analysis of the data is, at present, in progress.

The objective is to determine whether the proposed method could be useful as a tool for direct detection of ore and other deposits.

Over 350 earthquakes (distance 14^{o}-36^{o} and azimuth 0^{o}-360^{o} and about 50 events out to 70^{o} at an azimuth of 45^{o}-120^{o}) recorded at the Gauribidanur array (GBA) in southern India and over 100 earthquakes recorded at the Yellowknife array (YKA) (distance 12^{o}-30^{o} and azimuth 165^{o}-285^{o}) in Canada were analysed by A. Ram and R.F. Mereu using adaptive processing techniques. The measured values of slowness and azimuths for the arrivals were compared with theoretical ones.

Anomalies from the GBA analysis in slowness of up to 1.3 sec/deg and in azimuth up to 8^{o} were observed. Slowness anomaly patterns for the Java trench, Mid-Indian Oceanic ridge and far east regions are more regular than the patterns from the Himalayan and Hindukush regions. The most significant feature of the azimuthal anomaly pattern was the distinct absence of any positive anomalies from Mid-Indian Oceanic ridge earthquakes. The anomalies from the YKA events did not show a consistent pattern in the two regions. The irregular pattern in these anomalies indicated that the ray paths from the west of YKA had penetrated complex lateral structures. Absence of any definite sinusoidal variations of

these anomalies as a function of great circle azimuth implied that there is not a simple dipping Moho either beneath the GBA or YKA arrays.

A two-dimensional model is being used by L. Mansinha and F.K. Maxwell to study the propagation of Rayleigh waves on a curved surface. Semi-conductor strain gauges having a gauge factor of approximately 40 have been found to be sufficiently sensitive to detect elastic waves. The sensitivity of the strain gauges is approximately 10 db less than that of piezoelectric transducers of similar contact area. Various filtering techniques are being employed to separate the Rayleigh waves from the body waves.

The installation of arrays of short period vertical component seismometers around the world during the last few years has allowed the ray parameter $dT/d\Delta$ to be measured directly instead of by the conventional method of smoothing and differentiating a travel time curve. Systematic deviations between measured slowness ($dT/d\Delta$) and theoretical $dT/d\Delta$ values have often been attributed to lateral variations in structure beneath the array. In a study by D.J. Hearty and R.F. Mereu the results of two seismic arrays located in eastern Canada approximately 1000 km from each other are presented.

A seismic network installed in the La Malbaie region of eastern Quebec by the Earth Physics Branch in Ottawa for the purpose of studying the local seismicity of the area was used as the first array to measure the slowness and apparent azimuth of signals relating to 18 telesiesmic events in the distance range 35^{o}-151^{o} and azimuth range 52^{o}-336^{o}. A consistent bias in slowness and apparent azimuth measurements was observed for rays approaching the array from the southern regions (i.e. ϕ = 181 -227). This bias can be explained by a thickening of sedimentary strata beneath the south shore of the St. Lawrence River as opposed to the outcropping Precambrian basement rock on the north shore. The sedimentary accumulation can be interpreted in terms of a sloping interface located under the array between sediments and Precambrian rock or a thick horizontal sedimentary layer underlying the south shore of the St. Lawrence River.

The second array used in this study was a tripartite array near London Ontario which became operational in 1975. The slowness, apparent azimuth and travel time results for 70 earthquakes (Δ = 27^{o}-96, ϕ = 13^{o}-337^{o}) recorded at this array were analysed on a regional basis. The rays approaching from a narrow azimuth range to the south (ϕ = 165^{o}-195^{o}) appeared to be affected by an east to southeasterly dipping structure under the stations while the signals originating in the remaining azimuth ranges (ϕ = 0^{o}-165^{o}, ϕ = 195^{o}-360^{o}) were apparently influenced by a northwesterly dipping structure located under the array. After considering the local geology of the area these lateral variations were interpreted in terms of a complex dipping Moho or deeper structure within the upper mantle.

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

(a) Heat Flow

U, Th, K and heat production data on a core B1-67, from the Brent Crater have been obtained and are now being analysed by C.C. Chang and A.E. Beck. A.E. Beck is studying the effect of climate on temperature gradients. It is well known that significant corrections to measured heat flow values are required in limited areas which have been subjected to the advance and retreat of ice-sheets. However, important activities such as the Wisconsin glacial cycle must have been accompanied by temperature changes of global extent. Therefore, even those continental areas which were not subject to glaciation may have suffered important mean surface

temperature changes, thus leading to the need to correct heat flow measurements made in such areas. Furthermore, there have been significant widespread changes in climate during the Holocene, leading to a need to correct for short term temperature changes as well.

Applying corrections to existing data for a surface thermal history for the Holocene and Pleistocene, it is found that correlation between heat flow values and borehole depths are significantly reduced, that both positive and negative correlations of heat flow with conductivity may be due to neglect of climatic corrections, and that many heat flow values, particularly from shallow holes (less than 400 meters deep), may need corrections of several tenths of a heat flow unit (several mWm^{-2}).

It is concluded that mean heat flow values for heat flow provinces, and continents as a whole, may be in error by as much as 30 or 40% and that the mean oceanic and continental heat flow values may not be equal.

Since many regions have thermal properties which vary with depth, a more complete picture will be obtained if the variable properties are allowed for in the solution to the heat flow equation. A.E. Beck and J.H. Blackwell of the Dept. of Applied Math have commenced work on this aspect, starting with the relatively simple linear case.

J.C. Conaway and A.E. Beck have developed a complete system for continuous logging of borehole temperature gradients. To meet the requirements of this system, a time-domain operator was derived consisting of a smoothing term, a deconvolution term (to compensate for lag due to the thermistor time constant and probe velocity), and a gradient term. When convolved with raw field data this combined operator will yeild directly a high precision, high resolution temperature gradient profile.

The prototype equipment developed for the field tests includes a thermistor probe on a 1 km cable, and a cable winch modified by the addition of a gold slip-ring assembly; the probe is lowered at a constant velocity by a variable speed motor drive assembly. The thermistor impedance is monitored continuously by a low-current digital resistance meter (3 samples per second), the output of which is recorded on magnetic tape for processing by digital computer.

The system was field tested in two partially cased, water-filled boreholes. There was good correlation between gradient logs and thermal resistivity profiles from laboratory measurements on core material, indicating that even in partially cased wells the gradient log is a good approximation of the thermal resistivity profile.

For a lowering rate of 18 m/min, the gradient profile exhibits a repeatibility better than $\pm 0.5^{\circ}C/km$. Comparison of the gradient profile with a fine-scale geologic log indicates a stratigraphic resolution threshold on the order of 2 m for a 10-20% thermal resistivity contrast. For isolated resistivity contrasts of 50-100%, the resolution is better than 0.5 m.

This system will be useful for engineering applications in the petroleum industry, for monitoring the return to equilibrium of a borehole, as an additional aid to core selection in terrestrial heat flow work, and for stratigraphic correlation. In addition, this system may prove useful in other research areas, such as oceanography, arctic permafrost investigations, and studies of groundwater hydrology and pollution.

(b) High Pressure Studies

High pressure melting points of oceanic basalts have been obtained by H.H. Schloessin. Experiments were performed between 35 and 55 kbars, i.e. well above the garnet transition. Indications of melting and solidification were obtained from electrical conductivity measurements and from differential thermal analysis. Contrary to existing measurements on melting of synthetic basalt powders at atmospheric pressure the electrical conductivity was found to exhibit premonitory decreases near the melting point. These decreases are transient and may be explained firstly, by changes in conduction mechanism from predominantly electronic to ionic and, secondly, by the specific effects of partial melting due to latent heat absorption and disruption of the contiguity of the solid phase matrix. The extent of partial melting has been determined by a comparison of X-ray absorption topographs taken before and after high pressure exposure ($\Delta T/\Delta P$) values for the solidus follow closely the garnet line and the slopes of the diopside - clinopyroxene melting lines.

The electrical conductivity of oceanic basalts is being studied by H.H. Schloessin and Z. Dvorak. By a combination of high pressure and high vacuum experiments, the separate effects on the dc electrical conductivity due to pressure, temperature, and H_2O adsorption and desorption have been determined. A series of experiments on Joides Leg 37 samples has been completed. Results show that at 16°C and 10^{-7} torr the conductivity of basalt is of the order of 10^{-14} $(\Omega\ cm)^{-1}$. Raising the H_2O vapour pressure from zero to saturation increases the conductivity to 10^{-6} $(\Omega\ cm)^{-1}$. A change in conductivity of the same order of magnitude can be accomplished by heating a dry sample to 450°C-500°C. Quasi-hydrostatic pressure of 50 kbars increases the conductivity of dry basalt, at most, by 1½ orders of magnitude and more typically by a factor of 3.5.

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III HYDROLOGY

Compiled by: Dr. I.C. Brown
Executive Secretary
Associate Committee on
Hydrology

The Associate Committee on Hydrology fulfilled its responsibility to advise on research and development requirements in the field of hydrology by drawing on their combined competence to define the following four areas as those most in need of greater effort on a national basis.

Snowpack - Processes and Measurement - The spatial and temporal processes of snowpack formation, metamorphism and melt; snowmelt contributions to stream runoff, soil moisture and groundwater recharge; the effect of soil moisture on snowmelt runoff; the correlation of the processes with ground cover and relief and with meteorological parameters; the variations in these processes particularly in regions of shallow variable snowcover; improved methods of measuring snow parameters at a point and extrapolating to aerial data.

Effect of Man - Development of methods of assessing the effects of man's activities on different components of the hydrological regime in terms that can be used in hydrological models for forecasting and studying these effects. Specific information is needed on the hydrological response to those activities resulting in changes in water quality, erosion and sedimentation, and water quantity.

Precipitation - Measurement and Analysis - Improvement is needed in methods for directly measuring or calculating precipitation so as to provide information on the spatial and temporal variation of rainfall and snowfall on a real time basis, particularly in remote areas. Such information is needed for input data to hydrological models used to study and forecast basin runoff.

Groundwater - Quality and Contamination - Determination of practical methods of detecting, preventing, tracing and overcoming groundwater contamination from inadvertent or deliberate disposal of waste products on or near the ground surface and in deep wells. Information is needed on the effects of salts from artificial and natural sources on groundwater quality and the effects of groundwater discharge on the quality of surface water and land salinization. Knowledge of these processes is needed particularly in relation to groundwater in fractured rocks.

The ACH through its sub-committees started preparation of five state-of-the-art reports relating to the hydraulics of ice covered rivers and expected to lead to a comprehensive document with particular emphasis on Canadian conditions. Another sub-committee commenced a study on the status of hydrology education in an attempt to see if it was fulfilling the requirements of user agencies. An analysis team was set up to test data from the International Hydrological Decade Basin Program against various models to see how much that had been learned in these basins studies could be transposed to other areas and to assess the usefulness of basin studies.

Cold Climate Hydrology continues to receive considerable emphasis in Canada as a result of the exploration and development activities in northern Canada. Awareness of problems already encountered in the management of water resources has resulted in Conferences such as the Second Conference on Soil Water Problems in Cold Regions, held in Edmonton on September 1-2, 1976, sponsored by the American Geophysical Union. The Eastern and Western Conferences were of considerable interest to many Canadians. The Western Snow Conference was held in Calgary April 19-22.

Much of the effort in remote sensing applied to hydrology is being directed at determining snow cover and developing means of determining snow

water content. The Canadian contribution to the WMO Snow Studies by Satellite Project was brought to a successful conclusion with presentation of five reports at the international seminar held in Geneva in October 1976. Two major problems arising are the need of an all weather capability and the need to be able to identify snow under tree cover. Snow cover mapping is probably closest to operational use of any remote sensing in hydrology.

A workshop on Remote Sensing of Soil Moisture and Groundwater was held in Toronto, November 8-10, 1976. The state-of-the-art does not seem to have progressed very far since the launch of LANDSAT in 1972. On the other hand technology is progressing at an almost unbelievable pace. The main applicability of remote sensing still appears to be classification and inventory survey. Interpretation of sub-surface features, with the exception of conventional geophysics, is primarily accomplished by inference from features or characteristics of land surface or vegetation. Depth penetration remains in the realm of research using longer wave length electromagnetic radiation. Measurement of soil moisture using radioactive means can be classified as almost operational for the most part, although the transfer of this technology to airborne status is still in the experimental stage. Some promise for the measurement of soil moisture on an airborne basis appears to exist in the microwave frequencies.

Increasing interest in groundwater quality in Canada is evidenced by presentation of 12 papers at the Edmonton meeting of the Geological Association of Canada dealing with topics on groundwater pollution problems, natural groundwater quality, groundwater sampling methods, computer simulation of aquifer diagenesis and geochemical research techniques. A strong groundwater quality research program has developed at the University of Waterloo where the departments of Civil Engineering and Earth Sciences are working on sanitary land fill leachage migration, computer simulation of mass transport processes, radionuclide sorption by typical Canadian soils, nitrate pollution of groundwater and carbon isotope geochemistry. A diverse group involving Atomic Energy of Canada Limited, Inland Waters Directorate, University of Waterloo, and Queen's University are studying the geohydrologic and geochemical controls on radioactive waste migration in a sandy aquifer at the Chalk River Laboratories. In Quebec the Ministère des richesses naturelles has promoted the use of groundwater age dating procedures in aquifer management. In Nova Scotia and New Brunswick arsenic in groundwater has become a major public health problem and provincial hydrogeologists have undertaken groundwater surveys to determine the source of the pollution.

The Inland Waters Directorate is continuing its work on spring-water geochemistry and has initiated a study of the groundwater contribution to irrigation return flows in collaboration with Agriculture Canada and the Alberta Environment and Agricultural departments. Alberta Environment has been studying the flow of radionuclides through fractured till and the field dispersion of sanitary land fill leachate. The University of Alberta has published several papers on the simulation of radioactive waste migration. The Alberta Research Council has been investigating regional facies in groundwater quality.

Groundwater flow modelling studies continue and the models and numerical and analog models are utilized as tools for management of groundwater resources in Ontario, New Brunswick and Saskatchewan.

Increasing consideration has been given to stochastic problems and uncertainties in hydrogeologic modelling. The effect of uncertainties in hydrologic knowledge on predictions based on consolidation theory has been examined at the University of British Columbia. The Inland Waters Directorate has taken a similar look at the effects of heterogeneity on the estimation of hydrogeologic parameters, and also sponsored an attempt to develop a combined theory incorporating both deterministic and stochastic elements into a single flow model. The growing interest in this research area and the pioneering

work that has been based in this country have led to the organization of a 1977 Penrose Conference to be held in British Columbia and intended to explore in detail the theoretical and practical implications of uncertainties in hydrogeological knowledge.

Attention is being paid to the hydrogeology of the Canadian North, in particular to the permafrost-groundwater system and its modification due to changing surface or near-surface conditions. An important component of such studies is the Inland Waters Directorate's continuing reconnaissance of groundwater related phenomena in the Canadian North. Such phenomena include springs, icings, seepage areas and stretches of unfrozen river water in winter. Satellite imagery has been used in observing the seasonal growth and decline of some of the larger of these features. Numerous other studies relate to the north in particular the seasonal migration of the boundaries between the permafrost and groundwater zones, the development of instrumentation capable of recording this under severe climatic conditions, and studies of water migration and transport through freezing soils.

Groundwater aspects of major earth moving activities, such as open pit mining, are starting to receive attention. An important theoretical concern here is the validity of the application of commonly accepted engineering formulae to the determination of, for example, slope stability. These formulae assume hydrostatic conditions whereas groundwater flow systems are dynamic and result in the generation of dynamic force fields that may be of considerable importance in practical engineering problems. Conversely major earth moving operations can disrupt local and regional groundwater flow systems and thus affect the quality of waters in receiving lakes, rivers and streams.

IV(A) GEOMAGNETISM

Compiled by: D.I. Gough

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

1. Geomagnetic Surveys - Earth Physics Branch

(a) Hudson Bay Survey

As part of a continuing multi-disciplinary survey of Hudson Bay, in cooperation with MOT, aboard the CCGS Narwhal, approximately 12,800 line kilometres covering parts of southern Hudson Bay were compiled between July 17 and August 26, 1976. A Barringer proton-precession magnetometer was used to obtain continuous (10 second interval) magnetic measurements on magnetic tape, over predominantly east-west tracks spaced 45 km apart. The fish containing the magnetometer coils was towed on a cable 110 m behind the ship, which is about 1.5 times the ship's length.

From the previous year's work, described in Geophysical Bulletin No. 28, 20,000 line kilometres were completed. Unfortunately, the PPM was operable only over the last half of the survey, and about 5,000 usable total force values (5-minute average values) were obtained. Preliminary profiles have been drawn but some correlations for magnetic disturbance still have to be made. Preliminary indications are that the largest anomalies occur in the vicinity of Cape Smith and central Hudson Bay. However much more detail is required from future surveys before attempting to correlate profiles with basement topography, sedimentary thicknesses and depths to basement.

(b) High-level aeromagnetic survey

A three-component airborne magnetometer survey of Quebec, the Atlantic Provinces and the Atlantic Continental Shelf was made during the months of September and October, 1976, at an altitude of 3 to 5 km. The flight lines ran approximately north-south, with a line spacing of the order of 75 km. The total estimated line flying was 85,400 km, 73 percent of which was actual survey lines.

This survey was the last of the high-level airborne surveys initiated by Earth Physics Branch in 1953 to cover Canada and adjacent waters in particular and make significant contributions to world magnetic coverage in general. During this period over 1 million survey line-km were flown and approximately 24,000 five-minute average values in DHZ collected.

Prior to 1965, the primary objective of this work was the compilation of data for the production of regional magnetic charts and contributions to world magnetic charts. Since 1965, these objectives were enlarged to include the study of broad scale magnetic anomalies and the line spacing was reduced from 100 km to 30-70 km depending on the area. These high-level surveys have been able to help delineate tectonic zones, and to suggest areas where closer magnetic investigations could be of considerable interest.

(c) Three-component land and ice survey of Kingston Harbour and approaches

During the winter of 1975-76, 24 stations were occupied in this area, and measurements of D,I and F taken. Seven of these stations were on ice, and a further 9 stations (F-only) were occupied in the vicinity of the anomaly centre. Over an area of 1750 sq. km., magnetic declination ranged from 8.2° west to 16.5° west; magnetic inclination ranged from 71.8°N to 74.5°N, and total force ranged from 56500 nT to 61000 nT. This work will be completed this winter.

2. Interpretation of Magnetic Surveys

(a) Dalhousie University

Newfoundland Basin - Studies continue of the spreading history of the Newfoundland Basin, west of magnetic anomalies 31-32 to the J(?) anomaly east of the margin of the Grand Banks. Scientists: C.E. Keen (Atlantic Geoscience Centre), M.J. Keen (Dalhousie), B. Hall (Dalhousie), K. Sullivan (Dalhousie).

Baffin Bay - Studies continue of the magnetic anomalies in Baffin Bay in an attempt to seek a clearer understanding of the spreading history of the Bay and the surrounding continental regions of Canada and Greenland. Scientists: R. Falconer (A.G.C.), D.I. Ross (A.G.C.), P. Newman (Dalhousie), K. Appleton (Dalhousie).

(b) Earth Physics Branch

Examination of the airborne three-component magnetometer data obtained during 1969, 1970 and 1972 has continued. Interpretation work on the 1974 survey over central Canada is delayed owing to the intricacies of the disturbance corrections.

Much of the preliminary work relating long wavelength components present in both the airborne and satellite magnetometer data to large scale lithospheric structures has been referred to in Geophysical Bulletin No. 28. Coles et al. (1976a) have produced a contour map of vertical magnetic field residuals, relative to the IGRF over western Canada and the adjacent Arctic regions. The map shows the form of the field within the waveband 30 to 5000 km. In addition to features mentioned in the previous Bulletin, a broad correlation between the heat flow pattern and the occurrence of intense magnetic anomalies near the western edge of the buried Shield suggests that these anomalies may be the result of an increase of viscous magnetization at elevated temperatures.

The results of joint study with personnel of Goddard Space Flight Centre, NASA, on comparisons between POGO satellite and airborne magnetic data were presented by Coles et al. (1976b) at the Fall meeting of the AGU. There is good agreement between the two data sets at longer wavelengths. The relations between anomalies observed at satellite altitudes and those observed at low altitudes are quiet complex. The comparisons between these data resulted in improved data reduction.

The results of a joint study with personnel of GSC Vancouver, on correlations between vertical component residuals, rock magnetic properties and the geology in the southern Coast Mountains, B.C. has been submitted to Can. J. Earth Sci. for publication. A qualitative correlation is observed between the northwesterly trending Coast Mountains Magnetic Anomaly, B.C. and a systematic, cross-trend variation of measured magnetization within the more mafic rocks from the Coast Plutonic Complex between 50° and 51°N. This variation partly determined the form of the anomaly. However, quantitative models indicate the presence of deep, intense magnetizations below the western Coast Plutonic Complex which may

be associated with mafic rocks at the surface. A magnetic crust as much as 40 km thick is consistent with geothermal studies in this region.

The origin of the Manicouagan structure, a roughly circular feature in Quebec, at 51°23'N, 68°41'W, within the Grenville geologic province was subjected to a multi-disciplinary investigation by EPB staff. A report of the magnetic investigation has been submitted for publication. The total intensity magnetic field over the area was measured systematically with aeromagnetic surveys by the Geological Survey of Canada and the Quebec Department of Natural Resources. The flight lines were approximately 0.8 km apart and 300 m above ground level. Three-dimensional modelling of the prominent (2000 nT) magnetic anomaly at the centre indicates the presence of highly magnetic rocks close to the surface over an area roughly 8 x 12 km. A localized, impact-generated magnetization, produced in an underlying extensive mafic rock unit, with subsequent uplift, is suggested as the cause of the feature.

Earth Physics Branch - Victoria Geophysical Observatory

A re-interpretation by R.P. Riddihough of the marine magnetic anomaly map of Raff and Mason over the Juan de Fuca and Explorer ridges of the north-east Pacific Ocean has enabled a detailed spreading history of these ridges over the last 10,000,000 years to be constructed. Consideration of the vector interactions resulting from these movements shows that many of the tectonic features of the area and the adjacent continental margin of British Columbia are directly explicable in terms of plate tectonics. Of the more important concepts and features that are emerging from this study are: the stability of the triple junction near the north end of Vancouver Island; the continuous but varying rates of subduction along the Vancouver Island margin; the role and influence of the Sovanco fracture zone both offshore and in probable eastward extensions which may be intermittently active in the lithospheric slabs descending beneath the continent.

(c) Université Laval - Interprétation de levés magnétiques

M.K. Séquin a terminé l'étude des cartes aéromagnétiques de la région du Mont Albert (Appalaches du Nord du Québec). L'interprétation effectuée dans les domaines spatial et des nombres d'onde a été entreprise en collaboration avec un groupe d'une quarantaine d'étudiants sous-gradués de Génie Géologique, de Génie Physique et de Géologie.

Cette analyse détaillée qui compte un grand nombre de courts profils magnétiques a permis de déterminer les dimensions (longueur, largeur, épaisseur, extension vers le bas), l'attitude (direction et pendage) ainsi que les propriétés magnétiques (moment et susceptibilité magnétique) des diverses masses causitives. On a alors comparé le modèle géologique obtenu avec celui résultant des données gravimétriques.

(d) University of Manitoba

A programme of interpretation of the extent of deep magnetic units in the crust is being carried out by D.H. Hall following the improved understanding of the structure of the English River-Gneiss Belt gained by geologists of the Pre-Cambrian Centre, University of Manitoba, during the course of the recently concluded negotiated development grant.

3. Magnetic Charts and Compilations

(a) Earth Physics Branch

Ozalid copies of a regional magnetic chart of western Canada, Arctic Islands and adjacent areas showing large scale anomalies in the vertical

component with respect to the IGRF are available, at a scale of 1:5,000,000.

A report on the series of magnetic charts of Canada, D, I, H, Z, F, scale 1:10,000,000, has been accepted for publication by Can. J. Earth Sci. (Dawson and Newitt, 1977).

(b) University of Toronto (D.W. Strangway, A. Gubins and J. Bambrick)

Two projects are now underway. The first of these in an M.Sc. study by Mr. Gubins on magnetic gradiometry. He is developing interpretive techniques and has applied these to a number of examples. He takes delivery of a prototype gradiometer in January which will be used for a number of studies including mapping of ancient meteorite crater features. The second project is just getting started and involves an attempt to study the magnetic signatures found within a greenstone belt. These signatures will be correlated with a number of geological and geochemical parameters.

4. Magnetic Observations and Instruments

(a) Earth Physics Branch

The development of a large demagnetizer for AF cleaning of paleomagnetic rock samples got under way in 1976. The design was completed and nearly all of the component parts have been fabricated. Initially a maximum demagnetizing field of 4000 gauss is expected, and eventually this will be increased to 10,000 gauss by enlarging the power supplies. Assembly and testing should begin in January 1977.

Geomagnetic and magneto-telluric data which is recorded on cassette tapes can now be verified at field sites, using a transcriber which was designed and built to read the cassettes and print the data on a paper roll.

The basic prototype of a new-generation Automatic Magnetic Observatory System has been designed, built and tested. The new system is based on a microprocessor which at present simply replaces the control logic of existing systems but which will eventually be expanded to perform quality checks on the data before it is recorded.

In co-operation with the International Magnetospheric Study, three-component magnetometers with digital data loggers which sample the field every ten seconds were built and put into operation at eight temporary stations along or near the geomagnetic meridian through Churchill Manitoba. These stations form a chain which extends northward through the auroral zone from the permanent magnetic observatory at Shell Lake Manitoba to Pelly Bay, N.W.T.

Eleven (11) magnetic observatories were in operation in 1976: Mould Bay, Resolute Bay, Cambridge Bay and Baker Lake in the Arctic; Yellowknife, Fort Churchill and Great Whale River in the auroral zone; Victoria, Meanook, Ottawa and St. John's in southern Canada.

At all observatories except Mould Bay an Automatic Magnetic Observatory System (AMOS) records the three orthogonal components (X, Y, Z) of the magnetic field plust total intensity once a minute in digital form on magnetic tape. The tapes are sent to Ottawa at the end of each month for editing by computer. Daily checks are made from Ottawa, of the operation of the AMOS installations by means of a telephone verification system. Standard photographic magnetograms are produced by all observatories except Cambridge Bay, Yellowknife and St. John's. For these stations magnetograms in standard format are constructed by plotting the

edited one-minute digital values. Similar plots are also made of the AMOS digital data recorded at the variation station Whiteshell, Manitoba.

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

Microfilm copies of magnetograms for all observatories, and for the variation stations at Alert, Ellesmere Island, and Whiteshell are sent monthly to World Data Centre A, Boulder, Colorado. Edited versions of the digital magnetic tapes containing minute values, mean hourly values and hourly ranges for one year for each observatory are sent to World Data Centre A on a yearly basis. Copies of magnetograms and raw or edited digital data may be obtained on a cost-recoverable basis from the Division of Geomagnetism, Earth Physics Branch, Department of Energy, Mines and Resources, Ottawa, K1A 0Y3. (E.I. Loomer)

A cooperative program with Dr. Potemera of John Hopkins Applied Physics Laboratory resulted in an automatic tracking facility at Resolute for the polar orbiting TRIAD satellite. The satellite-based magnetic data complements the Churchill meridian chain magnetic data so both the electrojet and the Birkeland field-aligned currents can now be determined quantitatively. (J.K. Walker)

(b) University of Manitoba

The Geophysics Section, Department of Earth Sciences, University of Manitoba, continued to operate the geomagnetic station at Star Lake, Whiteshell Park, under contract to the Federal Department of Energy, Mines and Resources.

5. Magnetic Disturbance and Pulsations

(a) Earth Physics Branch

Bays and Pulsations - J.C. Gupta completed his study of pulsation substorms and bays at high latitudes using Fort Churchill magnetograms for the years 1964 ($\overline{R}$ = 10.2) and 1970 ($\overline{R}$ = 102.4). In cooperation with D.R.K. Rao he also analysed Fort Churchill Pc5 pulsation data for 1962-1972, encompassing almost a complete solar cycle. Some of the more important characteristics noted are: 1) the periods of Pc5 pulsations show strong correlation with increasing sunspot numbers and the amplitude and occurrences are found to vary with the level of magnetic activity all through the cycle; 2) annual and semi-annual variations of Pc5 parameters have been demonstrated for pulsations occurring near the day-side magnetopause close to 8±1h LT and for those occurring near the midnight sector; 3) a 27-day recurrence tendency has been found for occurrence, amplitude and period of Pc5. Special large amplitude Pc5 pulsations (spacequakes) occurring during geomagnetically quiet intervals have been studied with many years of data from Meanook, Churchill, Great Whale River and Resolute Bay.

Solar and Lunar Variations - J.C. Gupta has made progress with the development of a computer program for obtaining solar and lunar geomagnetic variations using one minute digital data available from AMOS housed in several Canadian observatories. He has almost completed a complex program to compute solar and lunar geomagnetic variations from hourly data using Chapman-Miller method. This will be used to analyse long series of hourly data which has now become available on tape from several Canadian and foreign observatories.

(b) University of British Columbia - K. Hayashi, R.E. Horita, T. Oguti, K. Tsuruda, T. Watanabe, G.R. Nourry, H. Ueda and L.F. Zambresky.

Research activity of the Aeronomy Group during the past year was related to magnetic pulsations directly or indirectly. Continuous observation of magnetic pulsations was carried out at five locations in Manitoba for about five weeks of August to September of this year. This work was part of the International Magnetospheric Study (IMS). Induction magnetometers designed at UBC were used for the observations. A few basic experiments were carried out before the design was completed. On the theoretical side, analysis of Pc 2, 3 and 4 data obtained at a mid-latitude station was carried out in comparison with the solar wind field fluctuations observed by satellite. The obtained results indicate that pulsations of these types originate in solar wind.

IMS Project - In co-operation with Professor T. Oguti, Dr. K. Tsuruda and Dr. K. Hayashi of the University of Tokyo and Dr. R.E. Horita of University of Victoria, T. Watanabe carried out observation of magnetic pulsations in about a five week period from August to September of 1976 at five locations in Manitoba. They are as follows, from South to North: Star Lake, about 100 miles east of Winnipeg, Island Lake, Moak Lake, about 30 miles north of Thompson, Limestone, about 30 miles east of Gillam and Fort Churchill. A satisfactory quality of data was obtained at each station. Concurrently with the recording of pulsations, observation of aurorae using a TV camera system and of VLF emissions by a receiver having direction finding facilities were carried out by the University of Tokyo group at two locations, viz., Moak Lake and Fort Churchill. Analysis of the obtained data of pulsation, VLF and aurora have begun and have given a few interesting findings. Pc 1 activity was found to be highest at Island Lake. Pc 1 signals were seldom concurrent at the five locations. During a Pi 1 magnetic pulsation activity simultaneous with a pulsating aurora, chorus type VLF emission was found to be concurrent also and this was found to come from the same region as the pulsating aurora. One type of VLF hiss, daytime and continuous, was found to be independent of magnetic pulsation activity. The observation is planned to be carried out each summer during the next two or three years' period. The number of pulsation stations is planned to be increased up to about ten. Auroral and VLF stations will also be increased.

Instrumentation - The induction magnetometers used for observation of magnetic pulsations in the IMS project described above were designed by T. Watanabe with assistance and advice of the technical staff of the Department and many of his colleagues inside and outside UBC. The amplifier has a gain of 200,000 with a very low input noise level and d.c. drift, and a flat frequency response over an entire range of pulsation signals. With regards to sensors, two different types of coils were made. One is an air-core circular loop antenna, about 5 feet in diameter and 5,000 in turn number. The other is a solenoid, 50,000 in turn number and 18" in length, with a high-μ metal core. It is made of about fifty high-μ metal sheets, insulated and laminated, put together roughly in the shape of a cylinder whose normal cross section is about 1¼" in diameter. Both types of coils have a nearly equal absolute sensitivity which is about 0.05 Caner; an e.m.f. of 0.05 micro volt in amplitude is induced for sinusoidal magnetic field changes of one Hertz and of an amplitude of 1 milligamma.

During the field work, we found that the high-μ metal core solenoids are more convenient than the air-core loops. The solenoid coils have a self-inductance of about 1 kHenry and a d.c. resistance of about 2 k Ohm. The source impedance for 60 Hz signals, the main cause of noise, would be so high as to disturb performance of the amplifier. However, it was found that the difficulty can be avoided by putting a capacitor and resistor parallel to the input side of the amplifier. L. Zambresky demonstrated

that if capacitor and resistor of appropriate values are chosen, the sensor plus the amplifier input behave as a Butterworth filter of a second degree. For the field operation described above, we used a capacitor of 4.5 micro farad and a resistor of 10 k Ohm which made the corner corner frequency of the Butterworth filter 2.5 Hz.

H. Ueda carried out another basic experiment about sensors of an induction magnetometer. He examined performance of two different high-μ metal core coils, one having a core made of insulated and laminated sheets and the other a solid rod. He found that the self inductance of the first does not depend upon frequency up to 1 k Hz whereas that of the second begin to decrease at about 10 Hz. The insulated and laminated sheet core is clearly more desirable than the other.

Data Analysis - G. Nourry carried out analysis of magnetic pulsation data obtained at Ralston, Alta. during a three month period from August to October 1967 together with the concurrent solar wind plasma and field data obtained by two NASA satellites, IMPD and IMPF. It was found that abrupt changes in solar wind dynamic pressure give rise to damped oscillations of the Earth's magnetic field in a Pc 3/4 range whereas continuous pulsations in the same range are not related to solar wind pressure changes but to fluctuations of the interplanetary magnetic field (IMF). Spectral contents of ground-observed Pc 3/4's and concurrent IMF fluctuations are found to be strikingly similar. Even in the Pc2 range, some spectral peaks were identified with each other, although Pc 2 power level relative to Pc 3/4 is much smaller in case of ground-observed pulsations than in case of IMF fluctuations. A careful computation of occurrence-frequencies of Pc 3's and Pc 4's confirms the finding by Boshakova and Troitskaya that continuous Pc 3/4 activities are controlled by the average IMF direction. In computing the occurrence-frequencies, pulsation amplitudes were considered as a weighting factor. Besides, the occurrence-frequencies were normalized with respect to the IMF direction distribution. The outcome of the computation shows that Pc 4 depend on IMF directions more sensitively than Pc 3. It became clear also that Pc 4 occurs with an equal probability for either toward or away sector of IMF but Pc 3 has a significant preference for toward sectors. The results are explained in more detail in the Ph.D. Thesis by G. Nourry.

6. Electromagnetic Induction in the Earth

(a) Earth Physics Branch

Magnetotelluric studies in an area of induced seismicity - Due to the series of small earthquakes that were associated with the filling of the Manicouagan-3 reservoir, 80 km north of Baie Comeau, P.Q., the Earth Physics Branch became interested in attempting to predict a larger earthquake in the area should one occur. For this reason, monitoring the earth resistivity by the magnetotelluric technique at two locations near the reservoir began in December, 1975 with the cooperation of Hydro-Québec. One station is near the edge of the epicentral region and the second station serves as a control 30 km distant from the reservoir. Up to September 1976 no significant time changes in the resistivity have been detected at either station at periods ranging from 5 to 120 minutes. However the data provide a good background to which any future changes may be compared. Monitoring is continuing since earthquakes have occurred up to several years after filling at some other reservoirs throughout the world.

A third magnetotelluric station was established in October, 1976 on an island in the reservoir in the center of the epicentral region. Data are sampled once every 8 seconds and telemetered to the central recording site of the seismology array. No results have been obtained from the telemetered data at this time. (R.D. Kurtz)

Changes in Magnetic and Telluric Fields in a Seismically Active Region near La Malbaie, P.Q. - Honkura, Niblett and Kurtz (1976) have published the results of monitoring the time variations of impedance tensors over one year in a seismically active region near La Malbaie. Changes in amplitude and direction of up to 20% and 3° in the telluric fields were observed but no earthquake of magnetitude greater than 3 was recorded in the area. The changes were attributed to variations in salinity of the St. Lawrence River and/or to temperature changes. A reference station 67 km to the west, far from the St. Lawrence River, was established in October 1975 to test the above hypothesis. The impedance tensor elements at the reference station have shown no significant changes in amplitude over the past year. However the La Malbaie station has shown an impedance increase of up to 50% over five months starting in June, 1976. Simultaneous data from the two stations in the period range 5 to 60 minutes indicate the changes occurred mainly in the telluric field.

This work is part of an Earth Physics Branch Project to monitor a variety of geophysical parameters in this active region.

Geomagnetic Variation Studies on Banks and Victoria Islands, N.W.T. - From March 27 to April 28, 1976, 11 three-component fluxgate magnetometers were operated simultaneously on a 500 km line extending from north-central Banks Island to south-central Victoria Island. The data were digitally recorded on cassettes at one minute intervals. Polar Continental Shelf Project provided logistics and transportation in this area.

This project was a continuation of the 1974 line which extended out to 270 km over the continental margin of the Arctic Ocean. The present work was designed to further study the Mould Bay induction anomaly, to locate its eastern boundary, and to examine the inductive response of Victoria Island, in particular the Precambrian Minto Arch. The data has been played back and plotted, and analysis is in progress. (R.D. Kurtz and E.R. Niblett)

Magnetometer Array Studies - Major Fracture Zone (Possible Proterozoic Plate Boundary?) in North America.

P.A. Camfield and D.I. Gough (University of Alberta) have worked out a geological interpretation for the North American Central Plains conductivity anomaly. The anomaly was mapped in 1972 by a joint University of Alberta - Earth Physics Branch magnetometer array. Camfield and Gough believe that the conductor traces a major fracture zone, a possible Proterozoic plate boundary, from the exposed Precambrian in north central Saskatchewan to that in south-eastern Wyoming.

The northern extension of the conductor appears to be in line with the Churchill province Wollaston Domain, known from airborne e.m. surveys to contain many conductive anomalies with n.e.-s.w. trend. Many of the anomalies have been attributed to steeply-dipping graphite/gneisses and thin sheets of massive graphite. The Needle Falls Shear Zone, more than 1 km wide at the eastern edge of the Domain, is unresponsive to these surveys. The northern part of the conductor is coincident with a large magnetic high associated with the Domain.

The conductor links the Wollaston Domain to basement faults inferred beneath the sediments in the Venn Low and Regina-Hummingbird Trough of southern Saskatchewan, to a metamorphic belt in the South Dakota basement, to the Black Hills, and to the northern part of the Southern Rockies in Wyoming.

In the Southern Rockies, an exposed geochronologic boundary lies along the projected extension of the conductor. The boundary, defined by shear zones and igneous contacts separates the Wyoming Province (more than 2500

m.y. old) on the northwest from the Central United States Province (less than 1800 m.y. old). Hills (U.S.G.S.) and Houston (University of Wyoming) have interpreted the boundary as a possilbe proterozoic subduction zone. The continuity of the conductor and its association with the various geological features described above suggest a major continental fracture zone, relic of an ancient plate margin which once extended for more than 1400 km from Wyoming to Saskatchewan.

Saguenay - Laurentide Array, Quebec.

In 1975 the Earth Physics Branch (P.A. Camfield) operated an array of 23 borrowed Gough-Reitzel magnetometers in the Saguenay-Parc des Laurentides area north of Quebec City. The object of the rather small array (250 x 250 km) was a study of the crustal and upper mantle electrical conductivity in this region of high seismicity and rapid downward crustal movement. Visual inspection of magnetograms of substorms recorded simultaneously across the array does not appear to detect effects due to lateral conductivity contrasts of at least one order of magnitude so blatantly evident in the magnetotelluric signals recorded in the same area by Dr. R.D. Kurtz (formerly of the University of Toronto, now Earth Physics Branch). Work will continue with shorter-period events to try to resolve the discrepancy.

Other Induction Studies - The investigations of the Pemberton and Garibaldi volcanic belt has continued. Data have now been obtained at six sites along a NE-SE profile through the region. Correlation of the GDS results with heat flow data across the Cascade front is in progress. (L.K. Law)

In cooperation with the University of Washington Geophysics program digital geomagnetic data were recorded at five sites across Mt. Baker. Five second field samples are currently being analysed to determine if any unusually high conductivity areas exist under this strato-volcano which has several active steam vents. (L.K. Law)

The Mineral Exploration Research Institute, under contract, completed an audio magnetotelluric reconnaissance survey at three locations in the Lillooet Valley. Though geothermal effects at shallow depths were not found, many of the recording sites showed strong anisotropy with low resistivity in the N.S. direction and high resistivity E.W. The anisotropy may be caused by fracture zones associated with geologically recent rifting and vocanism. A highly conducting layer was found at a depth of 20 km suggesting the existance of high temperatures at this depth. (Pham Van Ngoc)

(b) University of Alberta

The electrical conductivity distribution in the solid Earth continues to be studied by the magnetotelluric method, by means of two-dimensional arrays of magnetometers and through numerical model calculations. Both magnetometer arrays and the magnetotelluric method can also be applied to studies of external currents in the magnetosphere and ionosphere; in this region the array studies of the Space Physics group are closely complementary to those here reported, and vice versa.

The North American Central Plains conductivity anomaly as a possible Proterozoic plate boundary - P.A. Camfield, D.I. Gough and A.O. Alabi.

A large magnetometer array operated in 1972 has yielded a map of the position of this narrow, highly-conductive crustal anomaly from the northern end of the Southern Rockies almost to the exposed shield in Saskatchewan, a distance of 1400 km (Alabi, Camfield and Gough, Geophys. J., 43, 815, 1975). Camfield and Gough recently completed an intensive

study of geological, geophysical and geochronologic data from the diverse region traversed by the conductor. Recent results on the Precambrian geology at both ends of the conductor, in the Churchill Province of the Shield and in southeastern Wyoming, support the hypothesis that the anomaly in electrical conductivity traces a major fracture zone in the lithosphere of Precambrian North America. The combined geologic, geochronologic and geophysical evidence tends to substantiate such a fracture zone or mobile belt. From the ages and compositions of rocks near the southern end of the structure, Hills and others suggest that a Proterozoic subduction zone is located there. It is possible that the entire fracture zone from the Southern Rockies to the vicinity of Hudson Bay, is a Proterozoic continental collision zone or geosuture.

Auroral zone array study of substorm and other transient fields - J.R. Bannister and D.I. Gough.

The observations were made in the late summer of 1974 with a two-dimensional array of 30 three-component magnetometers in northern Alberta and the adjoining part of the Northwest Territories.

From the resulting very large data set we have chosen for study three westward-electrojet substorms, one eastward electrojet, one westward surge and one eastward current transient enhancement. The technique of Fourier transformation, so powerful in induction studies in lower latitudes, proves less so here because the currents move on a time-scale of a few minutes and the integration over time in Fourier transformation thus loses vital information. Time domain maps averaged over 5 or 2 minutes ("time frames") are more informative. The data processing is complete and forward modelling studies are well advanced. In these we gladly acknowledge much help from Dr. G. Rostoker, Mr. T.J. Hughes, Dr. J.L. Kisabeth, Dr. D.W. Oldenburg and Dr. J.V. Olson of the Space Physics group.

Some "time frames" of the westward electrojet substorm fields can be modelled with a current loop having a horizontal segment crossing the array in the ionosphere, field aligned currents at the east and west ends and closure in the equatorial plane in the magnetospheric tail. Nearly all of the field is contributed by the ionospheric segment and the nearer field-aligned current, the latter being necessary for any reasonable fit to the data. Other "time frames" require a northwestward bend in the ionospheric current for best fit. Bannister has adapted programs by Kisabeth and Hughes based on use of the Biot-Savart law, and has applied them iteratively to an assumed model, varying a few parameters for optimal fit to the data on a least-squares criterion. In some "time frames" all three components can be fitted to 20% and most to 10% by remarkably simple models. Field-aligned currents give the simplest explanation of the D components found outside the limits of the electrojet; while uniqueness cannot be claimed, evidence for the field-aligned currents is strong in the sense that alternative hypotheses become tortuous. Induction in a superconducting Earth of reduced radius is included in all models. Work has begun on formal separation of the fields of internal and external currents by surface integration.

Southern Africa - South African National Physical Research Laboratory (J.S.V. van Zijl, J.H. de Beer and D.I. Gough).

The work flowing from the Southern African magnetometer arrays of 1971 was completed in 1975 and reported last year. In the first 1971 array study a very large conductivity anomaly was discovered just south of the array, beneath the Cape Fold Belt (Gough, de Beer and van Zijl, Geophys. J., 34, 421, 1973). Dr. Gough hopes to visit South Africa in 1977 and to take his magnetometers. As the NPRL group has now constructed a set of 25 Gough-Reitzel type magnetometers it is planned to study this Cape Fold Belt anomaly with an array of 50 instruments. It is hoped simultaneously

to study induction effects at the Atlantic and Indian Ocean coasts, which have tectonic origins related respectively to rifting and shearing.

Instrumentation and data processing - M.D. Burke, D. Chan, J.R. Bannister and Aziz-ur-Rahman.

The film scanner-editing system is now in routine use (Burke, Alabi and Gough, J. Geomag. Geoelect., 27, 425, 1975). It radically reduces the daunting labour of processing data from an array. The new clocks for the magnetometers, based upon the common quartz wristwatch with additional countdown and switching circuits, are under final test and will be installed for use in South Africa.

Magnetotellurics - D. Rankin, D. Kao and R. Sigal.

A study on the enhancement of the signal to noise ratio in magnetotelluric data has been completed. A method has been developed such that in some cases data of reasonable quality may, using a coherency criterion, be manipulated to yield results which are statistically close to those obtained from extremely high quality data, which in turn nearly always imply very small scatter. In those cases in which the scatter is not reduced, the analyses indicate that such results should be discarded. Considerable improvement in the consistency of interpretation has been achieved by the application of this method.

Statistically significant variations in apparent resistivities over relatively short times have been reported. A synoptic study is now being undertaken to evaluate this phenomenon. Since the University of Alberta's Geophysical Observatory lies in a tectonically stable region, an analysis of polarization parameters is being used in an attempt to differentiate between induction anomalies within the earth and anomalous behaviour of the ionosphere as a source of the variations. Concurrently the data enhancement technique is being applied to test the validity of the assumption of time variations in apparent resistivity in a stable region.

Micropulsation studies - D. Rankin and R. Sigal.

Theoretical studies on source and transmission problems are going forward. The effect of the ionosphere on the observed polarization pattern is being considered. The results will be used in an attempt to understand the anomalous results observed in the polarization properties of micropulsations at the surface of the earth. On the experimental side, the Pc 1 frequency range is being studied in particular detail.

Numerical Modelling Studies - F.W. Jones, R. Hibbs, V. Ramaswamy and L. Sydora.

A numerical modelling technique is being used to investigate the perturbation of electromagnetic fields by two-dimensional and three-dimensional conductivity inhomogeneities.

Three-dimensional numerical results are being compared with analog model measurements made in collaboration with Dr. H.W. Dosso and Mr. W. Nienaber at the University of Victoria and Dr. L.K. Law of the Dominion Astrophysical Observatory, Victoria. Numerical and analog model results for a Vancouver Island model are being compared with observational data.

Together with Mr. Hibbs, Dr. Jones is studying the effects of sources of finite dimensions in three-dimensional electromagnetic induction models. Uniform, two-dimensional non-uniform and three-dimensional dipole sources have been studied. Source effects on the perturbation and induction arrows associated with three-dimensional conductivity anomalies have been investigated. Also, Mr. Hibbs, with Dr. Jones and Dr. Ramaswamy

of the University of Alberta and Dr. H.W. Dosso at the University of Victoria have made comparisons between analog model results and numerical calculations for non-uniform source fields and a three-dimensional conductivity inhomogeneity.

Dr. Ramaswamy and Mr. Sydora with Dr. Jones have been concerned with the perturbation of geomagnetic fields at the surface of the earth above downgoing lithospheric slabs, and are pursuing a study of the relationship between the temperature regime associated with subduction zones and the perturbation of electromagnetic fields near such zones.

A numerical study is underway with Dr. F.E.M. Lilley of the Australian National University, Canberra, Australia in which the dependence of the field perturbations on the depth of a three-dimensional structure is being investigated.

With Dr. K. Vozoff of MacQuarrie University, North Ryde, Australia, Dr. Jones is studying the effects of three-dimensional conductivity structure on the apparent resistivity values calculated near such inhomogeneities.

Numerical Modelling Studies of the Thermal Regimes of Downgoing Slabs - F.W. Jones and L. Sydora.

The thermal regimes of downgoing lithospheric slabs in subduction zones and the associated surface heat flow are being investigated by Mr. Sydora and Dr. Jones using a numerical technique. The program is an extension of the Minear and Toksoz quasi-dynamic approach and is more general. Downgoing slabs of various dip angles may be considered as well as slabs that may change their dip angles at depth. Also, uprising material from the top of the slab may be included in the model. This project is in collaboration with Dr. R. Lambert of the Department of Geology, University of Alberta and the model is being used to study heat production and the effects on earth materials near subduction zones. With the model, zones of partial melting produced by the slab may be investigated as a function of the parameters of the downgoing slab.

Interpretation of Direct Current Resistivity Measurements - D.W. Oldenburg.

The theory of Backus and Gilbert has been used to invert the potential differences measured in direct current resistivity soundings. It is assumed that the resistivity is isotropic and a function of depth only. An iterative technique has been developed whereby potential differences from any electrode configuration can be inverted to construct a resistivity whose predicted responses are in agreement with the observations. Convergence of the iterative scheme is very rapid. The problem of non-uniqueness is solved by using the observations to provide information only about the average of the resistivity around any depth of interest. Knowledge of the Frechet kernels for the resistivity problem allows one to compare for the first time the resolution provided by different electrode configurations and to explore the possibility of designing the locations at which surface measurements are taken in an attempt to optimize the resolution of the resistivity at any depth.

(c) University of Toronto - R.C. Bailey, R.N. Edwards and G.D. Garland

During the year under review, emphasis was placed on developing and testing the controlled-source system for crustal sounding by electrical conductivity determination and on extending natural field surveys in the Northern Appalachians. The field work and interpretation of the former is forming part of the Ph.D. research of P.M. Duncan. He has been greatly assisted in the field and laboratory by technician Henry Urbanski. The

interpretation for this technique depends upon certain fundamental calculations, rather than upon any formulae available in the standard literature. R.H. Edwards is pursuing this aspect of the problem, assisted by student E. Trevino. We have been fortunate in having with us for several months Dr. A. Kaufman, formerly of the U.S.S.R., and extremely experienced in problems concerned with electromagnetic induction.

The field work and preliminary interpretation for the natural field studies in the northern Appalachians has been conducted by R.C. Bailey, also assisted in the field by Mr. Urbanski. In the report which follows the four sections cover the theory, field work and preliminary interpretation of the controlled source system and a description of the natural investigation.

Controlled Source System - Theory and Method

In the controlled source method, a time varying current is transmitted into a long, grounded wire or bipole. The resulting current flow in the earth is of two forms; - a pseudo-direct return current flow between the electrodes and an induced current flow. The direct current is useful for mapping regional, shallow conductivity anomalies. However, the presence of any resistive layer in the crust limits its usefulness for mapping any conductive structure at depth. The resistive layer screens the structures and very large current electrode separations must be used for the direct current to penetrate it. The time variation of the current overcomes this problem by producing a vertical magnetic field which induces eddy currents in any conductive layers at depth. The channelling of these currents by conductivity anomalies causes a perturbation of the observed electromagnetic fields and enables the anomaly to be mapped.

In geologically complex areas, many frequencies have to be transmitted to determine the electrical structure. If they are transmitted one at a time, the measurements have to be repeated many times to cover the spectrum adequately. This is an inefficient, time-consuming procedure which almost necessitates some form of verbal communication between the transmitter and the receiver. One alternative is to transmit a repeated step in time and stack the shape of the transient. This system is commonly used both in North America and the Soviet Union. Depending on the form of the background geomagnetic noise, the characteristics of the instrumentation and the nature of the geophysical problem, a sharp impulse of charge is a preferable form for the transmitted signal. But this results in the peak current transmitted being very much larger than the average current and it leads to an overdesign of the bipole system which clearly has to handle the peak current. A possible compromise is a signal of constant power whose autocorrelation is an impulse in lag domain. This is the basis of the VIBROSEIS technique for seismic profiling.

Such a signal, known as a pseudo-random binary sequence (PRBS), may be used to operate a double-pole, double throw switch between a direct current generator and the bipole. The transmitted current has a relatively flat amplitude spectrum from half the clock frequency fc, used to generate the PRBS, to the repetition frequency of $fc/(2^n-1)$, both n and fc being selectable variables. The autocorrelogram of the current function is a comb of triangles separated by $(2^n-1)/fc$.

In the experimental system developed at Toronto the two generators are locked together at the beginning of the day. One remains at the transmitter controlling the current, the other is carried with the recording magnetometer. At the recording site, the measured magnetic field is cross-correlated digitally in real time with the output of the local generator until an adequate signal to noise ratio is obtained.

Typical correlograms recorded in the field may be regarded as magnetic fields produced as a function of time due to a current in a bipole also varying as a function of time. Ideally, this "current wavelet" would be a perfect triangle. In practice, it differs from a triangle because the correlogram is limited to a finite frequency window by analogue shaping filters.

Controlled Source System - Field Work

The preliminary field tests of the controlled source apparatus continued at the Oshawa site throughout the winter and spring of 1975-76. Over this period, the equipment and measurement procedures were continually re-evaluated and redesigned. The objective was to attain a dependable and relatively portable version of the original system and to be assured of consistently repeatable results. The Oshawa line was reactivated by Ontario Hydro in July.

Meanwhile arrangements were made with Ontario Hydro for the use of a similar line in the vicinity of Timmins, which had been built in 1967 to serve the Kam-Kotia Mine. The closing of the mine in 1973 left the line idle and available to us. The line is oriented northwesterly and is very nearly straight over its 21 Km length. The southeastern end is on highway 101 about 9 Km west of Timmins. The easy accessibility of this end of the line served well for setting up the transmitter. The northwestern end is on the mine property just to the northeast of Kamiskotia Lake.

Two field trips were made to the Timmins area this season; the first in early June and the second in early August. Each was of just under three weeks in duration. As mentioned, the transmitter was set up daily at the southern end of the wire. The receiver and recording apparatus were transported to the various recording sites in a rented truck. Although the truck was equipped with four-wheel drive, the size and weight of the receiving equipment, combined with the swampy terrain, still limited measurements to those areas with fairly well-travelled roads.

The data collected during these two trips are in the form of 213 cross-correlograms each displaying 1 sec. of delay time. They were recorded at 55 different stations scattered over an area that reaches out to 50 Km on either side of the wire. Of these stations, about 42 provide useful data for the sounding experiment. Data from the others are contaminated by the effects of current apparently induced by our signal in nearby power lines. This effect was unexpected and several of these extra stations were established to delineate it. Of the 42 stations, 6 are to the west of the wire lying roughly on the line perpendicular to the midpoint of the line. The rest are to the east where obvious lateral variations in the results appeared to justify a greater number of observations.

At each station measurements of the vertical and horizontal (perpendicular to the wire) magnetic fields were made and repeated to assure consistency. Each correlogram requires 22 minutes collecting and averaging time. Making 4 such recordings at each station meant that after taking time for setting up and travelling between stations, there was usually only time to do 2 or 3 stations a day. Time lost to equipment failure reduced the average number of stations occupied per day over the entire trip to something less than this.

Cross-correlograms typical of those obtained in Timmins show a marked differences in amplitude between the signals recorded to the east and to the west of the wire. The eastern stations also show much more activity in terms of delay and widening of the correlograms. Perhaps even more interesting is the apparent amplitude versus distance inversion on the

eastern side. The observations must certainly imply substantial lateral variation in conductivity.

Currently, the data are being studied to determine exactly what this kind of anomaly, and others within the data, will reveal about the conductivity structure within the area.

Controlled Source System - Interpretation

An examination of the field data collected with the system reveals that the earth is not a plane layered structure! Numerical computer programs do exist for determining the effect of a grounded long wire source over an arbitrary, three-dimensional conductive earth. However, the programmes are expensive to run and for initial interpretation, we decided to divide up the interpretation into a series of less expensive steps. To date, the following steps are being completed:

(i) *The pseudo-direct current problem*

Over the last several years, we have obtained analytic solutions for the magnetic field due to a point electrode near conductors of simple geometry (Edwards & Howell, 1976). The work has been extended successfully to horizontal cylindrical structures of arbitrary cross-section. The latter project at first seemed quite difficult, involving integration over the volume of current flow. Using some elegant applied mathematics, the problem has been reduced to a few line integrals enabling accurate estimates of the magnetic field to be obtained very inexpensively.

(ii) *The 'impulse' response of a multi-layered earth*

Using the technique of Weiner filtering, the measured correlograms may be deconvolved from the current wavelet to yield the impulse response of the earth. These are being compared with type curves for a layered earth computed previously by Dr. Kaufman.

Needless to say, the overall interpretation of the field data is not going to be easy and will take some time.

Geomagnetic Sounding and Magnetotelluric Studies

Geomagnetic sounding studies can outline tectonic features by their electrical conductivity structure. This is particularly useful when the surface geological expression of these tectonic features is small or absent. The geomagnetic sounding program of the University of Toronto in eastern North America was undertaken with this in mind in 1970 and carried on to the present.

With new equipment constructed in 1975, measurements of the variations of the three components of the magnetic field were made at 18 locations in New York, Vermont, New Hampshire and Maine in 1975 (in conjunction with the University of Waterloo) and 1976. Electric field variation measurements were also made at about half of these sites. Recording was typically carried out at each site for several weeks. From this data, magnetic transfer functions relating the vertical to the horizontal magnetic variation at each site have been calculated for a number of different periods of variation. Magnetotelluric sounding curves have also been calculated for those locations where the electric field was measured.

The magnetic transfer functions have been used to calculate the vertical magnetic fields associated with "hypothetical events" (Bailey et al., 1974) and the resulting vertical fields contoured on a map of the area. The resulting contour maps are then interpreted by associating

large gradients with the edges of good conductors, the sense of the gradient depending on the sense of traversal of the edge and the sense of polarization of the "hypothetical event". A well-defined conducting region has been mapped in the New England states.

Similar conductors, extending seawards, have been found just off Nova Scotia to the north (Cochrane & Hyndman, 1974) and underlying the coastal plain in Virginia (Edwards and Greenhouse, 1975) to the south. The result presented here suggests that these may all be observations of a single long conducting structure underlying much of the eastern margin of North America, and that the edge of the structure crosses under the coast in southern Maine. Analysis of the Nova Scotian and Virginian data suggests a mid-to-lower crustal depth for the structure. Ancient oceanic crust or other hydrated rocks have been suggested as possible conductors by the above authors. The tectonic associations of the structure are still a matter for conjecture. It is possible that it may indicate an ancient continental suture.

Further work is intended on three aspects of the problem. Detailed modelling of the present results is required to confirm the similarity with the Nova Scotian and Virginian results; further field work is necessary to trace the structure between those regions which have already been studied; finally, an examination must be made of the possible tectonic associations of the structure (i.e. origin and composition) with the intent of using these results to help in clarifying the tectonic history of eastern North America.

Electrical Sounding in Permafrost and Glaciers - D.W. Strangway, A. Koziar, J. Rossiter, J.D. Redman and J. Wong.

Work on permafrost sounding was extended this year to include measurements by audiofrequency magnetotellurics (AMT), radio frequency interferometry and in situ probes to study the electrical structure in winter time. Previous work using AMT in the summer time suggested that the active layer was transparent. The winter time results were essentially unchanged and confirm that AMT sounding is an excellent method for determining permafrost thickness even in the presence of the active layer. The radio frequency sounding data showed also that the active layer had little influence on the results but that attenuation due to the properties of the permafrost itself, reduced the interference to very low values. This means that this method can only be used in high resistivity permafrost (10^4 ohm-m or more). At the same time, the measurement of the dielectric properties in the top meter of the soil showed marked changes between summer and winter due to the presence of moisture and clays. These data could be explained from the previously studied properties of permafrost as a function of temperature.

These results were presented at a conference on Water in Planetary Regoliths held in Hanover, N.H. A model to describe scattering in various glaciers and in permafrost is nearing completion and will be incorporated in Rossiter's Ph.D. thesis.

Crustal Sounding by Audiofrequency Magnetotellurics - D.W. Strangway, J.D. Redman and A. Kryzan.

Crustal sounding work was continued this year with two major new field studies. A regional study of the electrical structure in the Precambrian of the upper peninsula of Michigan was carried out. This study adds to our previous studies in Nevada, New Mexico and Wisconsin done as part of Project Seafarer for the U.S. Navy. We also completed a major survey in the Geotraverse area of northern Ontario paying special attention to differences between granites, gneisses and greenstone belts. In general, it can be said that the pattern of a highly resistive layer (up to 100,000

ohm-m or more) in the top few kilometers of the crust is typical of shield areas. Beneath this, the resistivity drops sharply, suggesting the presence of moisture in the middle crust. This work was presented at a crustal workshop held in Vail, Colorado. It appears that these low resistivities are correlated with low velocity and low Q portions of the crust.

Electrical Properties of Rocks - Terrestrial and Lunar - D.W. Strangway, S. Nowina, J. Wong, J.R. Rossiter and G.R. Olhoeft.

There is a continuing program of electrical property studies. We are continuing to examine the implications of the measured electrical properties of lunar samples on the nature of planetary sounding. This work is interpreting the radar returns from the planets and radiofrequency sounding results carried out on the moon. These results are explainable in terms of highly transparent materials which become highly scattering at high frequencies. Some results were presented at the Conference on Water in Planetary Regoliths.

Using the high vacuum system, Mr. Nowina has made measurements of the intrinsic dielectric anisotropy of a number of Precambrian samples from deformed regions of the shield. Using a simple model of series and parallel paths these properties can be quite readily described and clearly reflect the strain in the rocks. Analogous measurements of the magnetic susceptibility anisotropy give similar results.

A new effort to study the electrical properties of interfaces has been initiated. This effort will concentrate on the interface between semiconducting solids and between semiconductors and fluids.

(d) University of Victoria - H.W. Dosso, J.T. Weaver, C.R. Brewitt-Taylor, R. Chan, T.W. Dawson, V.R. Green, T. Miles, M. Nicoll and W. Nienaber.

Theoretical and analogue model studies of electromagnetic induction are continuing at the University of Victoria.

The numerical solution of problems in electromagnetic induction by the method of finite differences has been re-examined from a different point of view and a number of points have been clarified. A general computer program based on this method has been written and has been used, among other things, to extend previous calculations on the coupling of induced ocean currents with regions of high conductivity beneath the Earth's crust. The H-polarization mode of a problem of this type has also been obtained by the Wiener-Hopf technique. Progress has been made on a new numerical method for solving problems of induction in an Earth whose anomalous regions are confined to the surface layers.

The analogue model studies include the response of embedded conducting bodies, various aspects of the coast effect problem, and magnetic variations induced by ocean waves. In collaboration with Dr. S.O. Ogunade, University of IFE, ILE-IFE, Nigeria, the problem of a conducting sphere embedded in a layered conductor for an overhead vertical magnetic dipole source and for a uniform source is being studied both with aid of the analogue model and analytically. In collaboration with Mr. R. Hibbs, Dr. F.W. Jones and Dr. V. Ramaswamy, (University of Alberta, Edmonton) the effect of non-uniformity of source fields over a conductivity anomaly is being studied using analogue model methods and numerical methods.

Simplified island models (circular and square islands) consisting of an island near a continental coastline for the case of E polarization of the source field have been studied by analogue and numerical methods. An analogue model study for the H polarization case is underway. The study of channeling of electric currents through the straits separating Vancouver

Island and the mainland is continuing using analogue model measurements, magnetotelluric measurements, and numerical calculations. A scaled model of Vancouver Island and the surrounding region has been constructed and detailed model measurements have been carried out. These analogue model results are being compared with numerical calculations and with magnetotelluric measurements for pairs of stations. The island problems are being carried out in collaboration with Dr. L.K. Law (Earth Physics Branch, Department of Energy, Mines and Resources, Victoria), and in collaboration with Dr. F.W. Jones and Dr. V. Ramaswamy (University of Alberta, Edmonton).

The effect of the contour of a continental coastline, in the form of bays and capes, for near-by islands is being studied using model methods. It is planned to carry out a comparison of model results and actual field measurements.

An analogue model, employing mercury to simulate an ocean, has been constructed and detecting equipment developed for a scaled laboratory study of magnetic variations induced by ocean waves moving in a steady magnetic field. Good agreement between theoretical calculations and analogue model measurements has been established for the case of an ocean of finite depth. This model is now being used to study the effect of a sloping ocean floor and a coastline on magnetic variations induced by ocean waves moving in the earth's magnetic field.

7. Paleomagnetism, Rock Magnetism and Tectonomagnetism

(a) Earth Physics Branch

Our Lower Palaeozoic program started two years ago is progressing well. A study of the Botwood Group and Mount Peyton Batholith of Newfoundland has been completed and should be published soon. A study of the Leading Tickles Intrusion of Newfoundland is nearing completion. A study of Ordovician rocks from the English Lake district is now completed. A paper on the occurrence of a transcurrent motion in the Northern Appalachians and Caledonides during the Lower Palaeozoic has been published (see bibliography). A paper on the Lower Ordovician Connemara Gabbro Suite in Western Ireland has been submitted for publication.

Under investigation are the following Lower Palaeozoic rock units: the Coldbrook Group, the Greenland Group, the St. Georges Intrusives and the Mascarene Formation, all from New Brunswick; some Ordovician dikes from Gatineau Quebec, and Cambrian red beds from Cataret, France.

Several Precambrian and Archean rock units have been studied during the year.

Results that have been published in 1976 or are in press or will be submitted for publication are from the following rock units: the Rapitan Group, the Michikamau Intrusion, the Abitibi and Matachewan diabase dikes, rocks from the Central Labrador Trough, the Harp Lake Anorthositic Complex, the Gowganda and Chibougamau Formations, the Seton Formation, the Douglas Peninsula Formation, the Takiyuak Formation, the Peninsula sill, the Pearson Formation and the Jacobsville sandstones.

Precambrian rock units presently under investigation are: the Tsezotene Formation, the Catherine Group, the Cameron Bay Group, the Hornby Bay Formation, the Western Channel diabases, the Echo Bay Diabases, the Snake River Iron Formation, rocks from the Belcher Islands and Rapitan Group (new collection) all from the N.W.T. or Yukon. In addition there are the Mount Nelson Formation from B.C. and some Archean dikes from Labrador. Some Jurassic dikes from Newfoundland and rocks from the Charlevoix crater in Quebec are under investigation.

A study of Carboniferous sediments at Minudie Point, N.S. (geologically of Pictou or Riversdale age) has been completed and the results indicate that they are of Riversdale age, with the aid of a magnetic horizon marker. It is shown that the magnetic horizon marker is a valuable stratigraphic tool (in press; see bibliography).

Archean (2.7 - 2.3 Ga) and Lower Palaeozoic apparent polar wander paths have been sketched. Data from the Gowganda Formation indicate that the path probably executed a loop about the present-day pole 2.3 Ga ago. An Hadrynian Track has been discovered and a new solution to the Grenville problem has been offered. These ideas should appear in print in 1977. The results of the Connemara Gabbro suite show the usefulness of paleomagnetic data to study the history of major fold structures.

The listing and appraisal of world-wide paleomagnetic data is now complete and is available in five issues: Issue 3, Palaeozoic results; Issue 4, Mesozoic results and results from seamounts; Issue 5, Cenozoic results.

Maps showing the development of the Arctic Ocean are nearing completion and 30 global maps showing the displacement of the continents since the Middle Devonian have been prepared.

Some of the studies and works listed so far have been done in collaboration with members of other divisions within the Branch and scientists of the Geological Survey of Canada and other institutions. Their contributions are more properly acknowledged in the bibliography.

On the technical side, our cleaning techniques are rapidly changing. The old system of doing pilot runs on a few specimens from each site and then performing blanket cleaning at one or two alternating fields or temperatures has been virtually abandoned. All specimens are treated to step by step demagnetization and the steps are getting smaller and smaller. This increases immensely the amount of work but we are finding that much information is lost otherwise.

Chemical leaching is gaining momentum and it is proving to be the most efficacious technique for the separation of the different phases of magnetization of sediments. However, we are experiencing some technical difficulties. With low porosity rocks, we have not found a way of obtaining a rapid acid penetration rate. Another problem is how not to dissolve everything and everyone in sight with acid fumes.

We continue to experiment with a two-stage technique, that is, to apply two different cleaning techniques to the one specimen.

(b) University of Alberta

Precambrian formations - Three papers describing paleomagnetic results from the Great Slave Supergroup have now been published (by D.K. Bingham and M.E. Evans) and a fourth is in preparation. Results from the Stark and Tochatwi Formations imply relatively rapid plate motions some 2 billion years B.P. An alternative hypothesis, that these data emanate from an area of small-scale tectonic rotation requires testing, and future sampling is envisaged with this in mind.

Quaternary formations - Data from a 7 m stratigraphic section in southern B.C. (20,000 to 30,000 B.P.) have been analyzed by C.J. Oberg and M.E. Evans using the maximum entropy method. Well defined spectral peaks occur at periods of 2000 and 6000 years. The former is associated with clockwise looping, which is typical of westward drifting non-dipole sources. Furthermore its periodicity is close to that deduced from analysis of historical observations. A paper describing these results has

been submitted for publication. Further sampling on a finer scale is planned to see if secular variation patterns similar to the familiar London and Paris historical curves can be resolved in the geological record.

The particular stratigraphic section involved covers the time interval in which the Lake Mungo excursion, reported from Australia, occurs. We find no evidence for such an excursion, and this lends support to the suggestion that these events represent rapidly varying localized non-dipole sources in the outermost core.

Collections from several other sites in western Canada and the U.S. ranging in age from 12,000 to 40,000 years have been made. These are currently being processed.

The long-term nature of the geomagnetic field - The long-term nature of the geomagnetic field is of great interest to both geomagneticians and paleomagneticians. Evidence that it has always possessed its present dipolar pattern has been difficult to obtain. An analysis by M.E. Evans of compiled paleomagnetic data offers a new test for the dipole model. The test is based on the frequency distribution of the angle of inclination, which depends on the morphology of the field. In particular, for rotational symmetry, the field is purely zonal and can be represented as that of one or more axial multipoles. A compilation of 1271 paleomagnetic determinations of inclination, covering the entire Phanerozoic, yields a frequency distribution which does not differ significantly from the dipole pattern; and the chi-squared test indicates that all higher order multipoles must be rejected. These findings, which have now appeared in print, thus lend credence to the suggestion that the geomagnetic field has always been dipolar.

Origin of stable remanence - Previous work has demonstrated the potential significance of oxide grains behaving as single-domain particles due to subdivision by intergrowth structures, both magnetite/ilmenite and magnetite/ulvospinel. Results of this work by P.M. Davis and M.E. Evans has now been published. More recent, and still on-going, work returns to the alternative source of SD particles, namely, as ultrafine discrete oxide grains. Oxide particles of this kind have been grown by suitable heating of synthetic olivine powders. Several compositions have now been investigated by J.K. Park and M.E. Evans. The results support the contention that magnetic microparticles exsolved in the interior of silicates are a significant source of paleomagnetic signal.

Oceanic Igneous Samples - Microscopic and electron-microscopic investigation demonstrates that the strong, stable remanence observed in DSDP Leg 37 basalts resides in homogeneous dendritic oxide grains. However, during thermal demagnetization in air phase-splitting to magnetite/ilmenite intergrowths takes place but directions of magnetization are unaffected. Ultrafine phase-splitting not resolvable by ordinary light microscopy is often invoked to explain magnetic irreversibility during laboratory heating. Thus their identification by electron microscopy lends support to such explanations. This work is being carried out by M.E. Evans with the active collaboration of M.L. Wayman of the Department of Mineral Engineering, University of Alberta, and two papers describing it are currently in press.

M.E. Evans, in conjunction with A.G. Thomlinson of U.B.C., has documented the magnetic properties of 26 dredged basalt samples from Explorer Ridge. They possess just those properties required by the Vine-Matthews hypothesis; Koenigsberger ratios are generally greater than 10, remanence is high (average NRM = 1.5×10^{-2} emu cm^{-3}), and Irving's polarity test indicates that the polarity observed agrees with

the sign of the overhead anomaly in 20 out of 23 cases, with 3 indecisive cases. A paper reporting these results has been published.

Magnetic anisotropy and rock fabric - D.I. Gough, Aziz-ur-Rahman and M.E. Evans have studied 254 specimens from 82 stratigraphic horizons in redbeds of the Great Slave Supergroup. These rocks lie between 1900 and 1700 my in age but have undergone only low-grade metamorphism. Appropriate parameters of the principal susceptibilities indicate that the magnetic anisotropies of the Kahochella Group and Tochatwi Formation are related to the original sediment deposition with flow direction along the East Arm trend axis, i.e. NE-SW. The flow direction is in good agreement with estimates from cross-bedding by Hoffman, and with the triple-junction failed-arm hypothesis of Burke and Dewey. Only gentle folding is present in the sampled parts of the Kahochella and Tochatwi rocks. In the intervening Stark Formation folding is much stronger with some isoclinal folds and steep dips. Here the magnetic anisotropy is shown to be dominated by tectonic strain, with magnetic lineations along the fold axes almost equal to magnetic foliations. The dominant magnetic mineral in these redbeds is hematite. It is suggested that the observed relationships to depositional and deformational fabrics can be understood if the magnetic susceptibility is associated with the red coating on quartz grains or with a small magnetite fraction, rather than specularite grains. A paper has been submitted.

The evidence of magnetic anisotropy related to folding in the Great Slave Supergroup has led to an investigation designed to test the response of depositional fabric to progressive deformation. A collection of about 130 oriented samples has been made by Aziz-ur-Rahman, D.I. Gough and M.E. Evans from the Precambrian Miette group, in regions of progressively increasing deformation in a traverse that spans some 100 km perpendicular to the tectonic strike of the Canadian Rockies. Processing of these collections is currently underway. This study involves the collaboration of Dr. H.A.K. Charlesworth, Geology Department, University of Alberta.

Measurements have been made on 39 samples collected earlier by P.C. Boetzkes from an exposure west of Calgary which gives access to four folds in the Cretaceous Cardium Sandstone in the Rocky Mountain foothills. An additional 64 oriented blocks were collected by Aziz-ur-Rahman and specimens from all of these have been measured. The magnetic anisotropy shows a very strong relation to deformation even though the folding in this area is gentle.

(c) Geological Survey of Canada

Much of the work is done in close cooperation with GSC geologists in their field areas so that good geological control of the results is maintained.

Paleomagnetism - Precambrian - The work on the Richmond Gulf area (Quebec) - part of the Circum-Ungava belt - was completed. Stable magnetization was isolated for the coastal basalt (5 sites) and andesites-red sediments (7 sites) yielding (south) pole positions of 172E, 39N and 163E, 51N respectively. Collections were also taken on the Manitounuk Islands (N.W.T.) south west of Richmond Gulf and the Sutton Lake (Ontario) area west of James Bay.

A paper on the geology and paleomagnetism of the Archean Abitibi belt is being prepared by R.H. Riddler and J.H. Foster.

The Hopedale diabase dikes (Labrador) present a good example of great circle magnetization probably due to two components. K.W. Christie is examining the collection in detail.

The Brown Sound red beds (N.W.T.) are being studied by F.H.A. Campbell and G.N. Freda. Detailed work has isolated a stable remanence yielding a preliminary pole at 66E, 31N.

Work by W.F. Fahrig and D.I. Jones (University of Salisbury, Rhodesia) on Upper Proterozoic sediments and diabase is almost completed.

Early Aphebian east-west dykes in the district of Keewatin (N.W.T.) are being studied by K.E. Eade, W.F. Fahrig and K.W. Christie.

W.F. Fahrig is working on dyke samples from Lake Mistassini and from southern Greenland.

Paleomagnetism - Younger Rocks - A number of short studies on Quarternary magnetic stratigraphy were conducted by several people from the Terrain Sciences Division (GSC) and the National Museum and J.H. Foster (i.e. cores from Lake Ontario; Wellsch Valley, Saskatchewan; tills in Pakowki-Pinhorn area, Alberta).

Paleozoic basalts of the Robert's Arm Group, Nfld., collected by H.H. Bostock and E.J. Schwar, have yielded a complex magnetization pattern which is being analysed.

Other applications - Y. Fujiwara of Hokkaido University, Japan, participated in a petrographic study of komatiitic basalts from Cape Smith.

A study of DSDP Leg 37 basalt samples indicated that high intensity remanence magnetization with directions conforming to present field directions is carried by essentially single component magnetic mineralogy. Scattered directions and low intensity appear to correlate with multicomponent magnetic mineralogy due to oxydation.

A study on a norite (1900 Ma) and a diabase (1250 Ma) dyke contact near Sudbury (Ontario) yielded a depth estimate of the present level of erosion of 7 km $\pm$ 2 at the time of diabase intrusion. The estimate is based on establishment of a zone of hybrid magnetic directions in the norite 50 m from the diabase contact. Blocking temperature and allowance for VRM acquisition using Dunlop and Buchan's method yielded a maximum temperature of 450°C at 50 m from the contact. The thermal effect of the dyke is calculated to correspond to a temperature increase of 270°C. Consequently, the ambient temperature was 450-270 = 180°C which is thought to have corresponded to a depth of 7 km. At this time, this is the only quantitative method to arrive at depth of burial estimates in the Precambrian Shield.

(d) Université Laval

Fosse du Labrador - M.K. Séguin a continué les études paléomagnétiques entreprises depuis 1971-72 dans les secteurs sud et nord de la Fosse du Labrador. Dans le secteur sud qui a été affecté par l'orogénèse grenvillienne, les recherches paléomagnétiques en cours sont centrées sur une étude régionale des itabirites magnétiques. Cette étude qui est quasi terminée a été entreprise en collaboration avec D. Lafond (étudiant en maîtrise). Dans ce meme secteur localisé entre le lac Sawbill et le Mont Wright M.K. Séguin en collaboration avec B. Plante (finissant en génie physique) a terminé l'étude paléomagnétique détaillée du gabbro de Shabogamo.

Dans le secteur nord, l'étude paléomagnetique que M.K. Séguin avait entrepris avec G. Lambert (ingénieur-physicien) et qui couvre la région des volcaniques situées entre Fort McKenzie et Fort Chimo est maintenant complétée.

Appalaches du Québec:

(i) *Secteur sud*

M.K. Séguin a entrepris les premiers travaux paléomagnétiques de la région des Appalaches du Sud du Québec en 1973. Toutes le études paléomagnétiques effectuées dans la région de Thetford Mines sont maintenant terminées à l'exception d'une. Les études paléomagnétiques entreprises par M.K. Séguin en 1976 sont les suivantes:

- les laves coussinées du complexe ophiolitique du Mont Ham et d'Asbestos.

- les laves à coussinets et les grauwackes du Caldwell de la région du Mont Orford.

- les laves du groupe de Caldwell (Cambrien) au sud d'Asbestos.

- les roches volcaniques et formations de fer de la région de Sherbrooke.

Ces dernières études ont été entreprises avec P. Champagne (étudiant en maîtrise), M.A. Coté (ingénieur-physicien), R. Robitaille (étudiant sous-gradué) et P. St-Julien (professeur de géologie) respectivement.

(ii) *Secteur nord*

M.K. Séguin a continué l'étude paléomagnétique entreprise en 1975 sur les péridotites et laves coussinées de la région du Mont Albert en Gaspésie en collaboration avec J. Beaudin (étudiant au doctorat).

Deux nouvelles études paléomagnétiques ont été entreprises par M.K. Séguin dans les Appalaches du nord du Québec. La première a trait aux volcaniques siluriennes du lac McKay (Gaspésie centrale); elle a été entreprise en collaboration avec P.A. Bourque (professeur de géologie). La seconde, entreprise avec un étudiant sous-gradué (R. Robitaille) couvre un secteur important des roches volcaniques siluriennes de la Baie des Chaleurs, i.e., la région de Black Cape-New Richmond en Gaspésie sud et Pointe Verte au Nouveau Brunswick.

Nouveau-Québec - M.K. Séguin a entrepris une nouvelle série d'études paléomagnétiques dans la région de la rivière La Grande, nord du Québec. En collaboration avec K. Sharma du Ministère des Richesses Naturelles de la Province de Québec, on a échantillonné les grès et quartzites protérozoiques de la formation Sakami, les dykes de diabases du Protérozoique supérieur ou plus récents et des complexes ultrabasiques archéens des plus énigmatiques.

(e) University of Manitoba

D.H. Hall has completed the collection of oriented core samples in the Aulneau Peninsula, Lake of the Woods and along the Provincial Highways between Vermillion Bay and Red Lake, Ontario, and Thompson and Lynn Lake, Manitoba. Susceptibilities and NRM's have been measured.

(f) Memorial University of Newfoundland

Precambrian and Paleozoic paleomagnetism - Paleomagnetic work has started on diabase dikes of late Precambrian age from the Long Range Mountains of Western Newfoundland by G.S. Murthy, E.R. Deutsch, P. Guntur and K.V. Rao. Extensive sampling was completed during the summer. On the

basis of pilot studies using both stepwise A.f. and thermal demagnetization, two components of magnetization can be recognized. The south-easterly directed low blocking temperature (≈550°C) component with steep to intermediate positive inclinations is consistent with the A.f. pilot studies. A south-easterly directed high blocking temperature (≈650°C) component with shallow to intermediate negative inclinations is revealed in some specimens after heating to about 650°C and sometimes recognized after vector analysis of the directions after 600°C. Further work is in progress.

Work begun in previous years has continued with further sampling to augment the earlier collections. E.R. Deutsch collected samples from a suite of steeply dipping andesites and volcanic tuff beds of presumed early Caradocian age from Waterford County, Eire, with logistic assistance from the Dublin Institute of Advanced Studies. It is hoped that the results of the enlarged study, which is in progress, will provide evidence regarding a proposed Proto-Atlantic Ocean between western and eastern Ireland. K.V. Rao sampled 18 sites of the late Precambrian Signal Hill Group Sandstones from the Avalon Zone of Newfoundland with the aim of inferring the age of their metamorphism. K.V. Rao and E.R. Deutsch are continuing studies of the Swift Current granite pluton from the Avalon Zone in eastern Newfoundland. These pink equigranular granites are found to possess a moderately strong NRM direction northward with intermediate positive inclinations and with Q_n ratios less than 1.

G.S. Murthy is continuing studies of magnetic properties of the anorthosite massifs of the northern hemisphere. Stable remanence components have been isolated for various anorthosite bodies from Labrador, Norway and Newfoundland. Enough data are now available for an overview of anorthosite magnetization. Analysis of the results is in progress.

Another continuing project is the paleomagnetic study of granite intrusions in central Newfoundland. The ages of the granites are crucial in choosing one or another model for the tectonic development of Newfoundland and it is hoped that paleomagnetism can throw light on the problem of relative and absolute ages of these bodies. G.S. Murthy, during his work on collections from various localities in central Newfoundland, isolated stable remanence for Deadman's Bay, Locker's Bay and Middle Brook granites. Further collections were made of Cape Freels and Newport granites and of diabase dikes intruding Cape Freels and Deadman's Bay plutons and which in turn are intruded by the Newport pluton.

Mesozoic formations - K.V. Rao and E.R. Deutsch are studying the magnetic properties of 12 Mesozic lamprophyre dikes near Fortune Harbour in central Newfoundland. The mean NRM direction for all dikes is northerly with steep positive inclinations. Q_n ratios range from 0.1 to 20. AF demagnetization at 150 oersteds resulted in dike mean direction of 350, +65 with greatly improved precision. One dike's magnetization seem to be anomalous. Pilot thermal demagnetization, while revealing blocking temperatures to be in the range from 300 - 500°C, did not show any consistent pattern of directional change. High field IRM curves indicate magnetite or titanomagnetite to be the remanence carrier. The pole position corresponding to the optimum field direction is 83°N, 195°E (δp, δm = 5°, 7°, 11 dikes) consistent with Jurassic poles reported from other parts of the Appalachians.

G.S. Murthy is conducting paleomagnetic and rock magnetic investigations of a Mesozoic dike swarm from northwest Greenland in collaboration with the Greenland Geological Survey. The studies revealed that the dikes belong to more than one swarm separated by significant age difference. Fourteen dikes yielded a mean pole at 67½°S, 351½°E (A_{95} = 9°), probably of Jurassic age and five dikes yield a mean pole at 28½°N,

332^{o}E ($A_{95} = 14^{o}$), very different from the first grouping. Further work is in progress.

Rock magnetism: Domain structure

P. Guntur, G.S. Murthy and R.R. Patzold are continuing studies on methods to distinguish single domain and multi-domain carriers of stable remanence using synthetic samples of magnetite with controlled grain-sizes. Experimental investigations include the bias field dependence of ARM, obtaining the Rayleigh loops, high field hysteresis, K-T and M-T curves and other rock magnetic parameters.

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

Ultramafic rocks - J.P. Hodych is continuing studies of the magnetic properties and aeromagnetic expression of the Alpine-type ultramafics of Newfoundland. These studies have revealed a striking contrast between the magnetic properties of the ultramafics of the Central Mobile Belt and those of the Western Platform, even though both are thought to have been originally part of obducted oceanic crust - upper mantle slabs. The reasons for the contrast are being sought.

Instrumentation - All the investigations summarized above are being conducted at the Geomagnetic Research Laboratory of the Physics Department. A Schonstedt spinner magnetometer was recently acquired. Further, high field A-F demagnetization equipment, similar to that designed by Roy et al., Earth Physics Branch, Ottawa, has been set up; this is capable of producing fields up to 3500 peak oersteds. Provision has been made also for imposing anhysteretic remanent magnetization in samples in D.C. fields up to 5 oersteds.

(g) University of Toronto

Shock-induced remanent magnetization from the Slate Islands, Lake Superior - H.C. Halls.

Paleomagnetic investigations carried out on the Slate Islands this year have reinforced the previous conclusion (Halls, 1975) of the existence of a shock remanence, although in detail the picture is complicated by local tilting apparently after the shock magnetization was formed.

The paleomagnetic data together with geological laboratory and field observations are consistent with (but as yet do not demonstrate) the following sequence of events in chronological order:

- Propagation of a shock wave outwards from the centre of the island group.

- Formation of shatter cones, microscopic deformation features in quartz and feldspar and secondary remanence in country rocks, as a result of severe (more than 100 kb) shock compression and subsequent rarefaction.

- Local but widespread brecciation of country rock and block rotation, with breccia dike zones infilling or injected along contacts between allochthonous blocks.

- Formation of a thermal remanent magnetization in breccias caused by cooling after frictional heating during emplacement.

Further paleomagnetic work is planned to study in detail rock units which yield anomalous shatter cone orientations, in an attempt to prove the age relations between the secondary shock remanence and block rotation. Thermal cleaning experiments are presently underway to see if the secondary remanence can be used to estimate paleo-temperatures attained just prior to magnetic resetting.

The cause of the severe shock is presently ascribed to meteorite impact (Halls and Grieve, 1976) because the estimated pressures are about 1-2 orders of magnitude greater than those known to be associated with endogenous processes. The absolute age of the shock event is still unclear, although A_{40}-A_{39} studies in conjunction with R. Bottomley and D. York are continuing.

Paleointensity studies of Keweenawan Igneous and Baked Contact Rocks - Investigators: L.J. Pesonen, H.C. Halls and G.W. Pearce.

Paleomagnetic studies on Keweenawan rocks (1000 - 1200 m.y.) over the past 15 years have revealed an apparently well-defined magnetic stratigraphy composed of units with both normal and reversed polarity. There are at least two polarity changes in the Keweenawan sequence, of which the younger one (from reversed to normal polarity) has been detected throughout the Lake Superior region.

A characteristic feature of this reversal is its asymmetry; both magnetization directions lie in a single vertical plane, but the reversed (upward) magnetization has a much steeper inclination than the normal (downward) one. Of particular concern in the interpretation of Keweenawan paleomagnetism is whether this asymmetry is caused by a secondary remagnetization component or whether the change to shallower inclinations reflects a movement of the continent to lower magnetic latitudes. If the latter interpretation is correct, and the Earth's magnetic field during Keweenawan time was dipolar like the field today, the intensity of the field should decrease towards lower latitudes. On this model the difference in inclination between Normal and Reversed directions is such that the reversed paleointensity should be greater than the normal one by about 35%.

Paleointensity studies of normal and reversed Keweenawan igneous and baked rocks has thus been conducted to examine the credibility of the above model. Suites of oriented samples have been obtained from the Thunder Bay area, across about 25 intrusive contacts where Sibley/Rove sedimentary rocks are baked by Logan sills and dikes. Thellier-Thellier paleointensity curves have now been obtained for about 100 specimens. These curves are often very complex due to the presence of viscous magnetization (VRM) at lower blocking temperatures and/or physico-chemical changes at higher temperatures. Nevertheless, we have obtained some 35 reliable linear paleointensity curves, which suggest a higher paleointensity for the reversed epoch (mean of 23 specimens = 0.77 oe, range 0.29 oe to 1.36 oe) compared to the younger normal one (mean of 7 specimens = 56 oe, range 0.28 oe to 0.79 oe). This difference in paleointensity between reversed and normal rocks disappears when the results are reduced to the paleoequator using the dipole equation. The paleointensity data therefore suggest that the Keweenawan asymmetrical reversal is not caused by secondary magnetization but can be the result of the movement of the North American continent towards lower latitudes. This model will be tested by paleo-secular variation analysis - a third method which may yield independent evidence of latitudinal differences between Keweenawan normal and reversed magnetization data.

The distribution, orientation and shape of shatter cones from the Slate Islands, northern Lake Superior - Investigators: H.C. Halls and R.M. Stesky.

The orientations of striations on shatter cone surfaces have been measured from twenty localities on the Slate Islands, in order to obtain the shape and orientation of the cones. A least-squares iterative technique is used to obtain the cross-sectional shape in terms of ellipticity, the orientation of the cone axis and the cone angle. Results to date show that the cones preferentially point inwards and upwards toward the centre of the island group. There is increasing evidence that cones whose axes depart significantly from a radial azimuth have been subsequently rotated into their present position. The anomalous cone orientations are observed in areas where the local geology is conspicuously different from the regional trend and also where there are anomalous orientations in remagnetization circles suggesting rotation of both primary and secondary shock magnetizations. Two of these sites have been analysed in detail and indicate that a single axis rotation increases the conformity of all three observations with the regional picture.

The Slate Islands have yielded the first reported occurrence of elliptical shatter cones, and their formation is thought to be due to host rock anisotropy. The most elliptical cones are found in strongly foliated Archean metavolcanics, and the plane containing the cone axis and the maximum dimension of the cross-sectional ellipse is parallel to the foliation.

Further studies on the Slate Islands are planned to examine the effect of anisotropy and lateral changes in rock type on the orientation, size, shape and distribution of the shatter cones. Individual cones will be studied in thin section and with the scanning electron microscope to determine the influence of rock type, grain size, and heterogeneities on the development of these curious structures. Furthermore, other deformation features, such as microcracks, kink bands in mica, and deformation lamellae in quartz and feldspar, all of which can be used to determine the shock wave direction, will be studied to supplement the shatter cone orientation data.

A paleomagnetic study of Middle Keweenawan conglomerates, Lake Superior - Investigators: H.C. Halls, L.J. Pesonen and H.C. Palmer.

Alternating field magnetic cleaning in 50 oe steps to 1000 oe has been performed on 160 field-drilled cores taken from mafic volcanic pebbles within the Copper Harbor Conglomerate, at the eastern end of the Keweenaw Peninsula, northern Michigan. Samples were collected from three sites at similar stratigraphic levels along strike. NRM directions have a marked westerly bias, indicating that a secondary component with westerly declination is present. About 30-50% of the samples in each site show clear remagnetization circles, while the remainder give stable directions with random distribution. The remagnetization circles converge at all three sites, and the local direction of the secondary magnetization is estimated from the least-squares intersection point (Halls, 1976). When the conglomerate is restored to the paleohorizontal, the local secondary directions become virtually coincident (within 4^{o}) and the mean direction ($D = 280^{o}$, $I = +18^{o}$) yields a paleopole at Lat. 14 N, Long. 179.6°E. The remagnetization episode thus pre-dated tilting.

Samples which yield remagnetization circles are invariable of weak NRM intensity (less than 1×10^{-4} emu/cc), while stable samples have intensities above 1×10^{-4} emu/cc. Since the stable sample directions are random and the swinging ones have NRM directions concentrated in the western hemisphere of the stereonet, the secondary component is interpreted to be of chemical origin.

There appears to be an overall increase in the extent of magnetic overprinting westwards along strike within the conglomerate. Native copper concentration in underlying Portage Lake volcanics also increases westward, so it is possible that the secondary remanence was acquired during copper emplacement.

A further 70 cores were field-drilled this summer from mafic volcanic pebbles in the basal part of the great conglomerate in the Mamainse Point volcanic sequence, north of Sault Ste. Marie. Again asymmetry in NRM directions was found, but the majority of pebbles were resistant to $\overline{AC}_4$ demagnetization. The few samples with NRM intensity less than 1×10^{-4} emu/cc were the only ones to exhibit remagnetization circles. These circles are observed to converge and yield a secondary magnetization direction which is consistent with slight reheating or burial metamorphism following or during extrusion of overlying mafic volcanics. The direction of the secondary component after structural correction is about $D = 290^{\circ}$, $I = 35^{\circ}$ and is significantly different from that found in the Copper Harbor conglomerate.

The conglomerate data as a whole suggest there has been no single regional remagnetization episode, but rather local ones at different times. The much higher formation $\overline{NRM}$ intensities of Keweenawan mafic volcanic sequences (5.8 to 1.0×10^{-3} emu/cc) compared to those of remagnetized pebbles (less than 0.1×10^{-3} emu/cc) suggests that the asymmetry of Keweenawan polarity reversals is not caused by an unremoved secondary component of magnetization due to regional metamorphism.

Application of Paleomagnetism to the study of Mississippi Valley-Type Ore Deposits - Investigators: Frank W. Beales, E. Craig Jowett, G.W. Pearce and Yeeming Wu.

The development of theories of ore genesis is presently hampered by difficulties in determining the difference in time of formation of host rocks and ores. By relating the paleomagnetics of samples to the known apparent polar wandering curves for various ages of rock, we can both improve the polar wandering curves and make an estimate of the differences in age between the differing samples. The Mississippi-Valley-Type ore deposits commonly occur in relatively undistributed host limestones that rest upon the continental basement, and are therefore ideally suited to paleomagnetic studies. Samples from southeast Missouri, Central Tennessee, Newfoundland, Nova Scotia and Northwest Territories, have been studied. The NRM of both the limestone host rocks and ores are in general weak. However, by using extra large samples and measuring with a cryogenic magnetometer, reliable measurements can be obtained. Both the a.f. demagnetization and thermal demagnetization clearly indicate the existence of stable NRM. We are hopeful that with more paleomagnetic data being accumulated, especially the comparison between the host rocks and the ores, the evolutionary history of the ore deposits can be better understood.

Paleomagnetism of Canadian Quaternary Sediments - Investigators: G.W. Pearce, J. Westgate and K. Robertson.

There are many Quaternary sediment deposits in Southern Ontario. With the addition of John Westgate, an experienced quaternary geologist, to the University of Toronto staff, paleomagnetic examination of these deposits has begun with the initial work being on the Scarborough Bluffs sequences. Measurements will in most cases be done with the cryogenic magnetometer at Erindale College since the samples are fragile and may be destroyed by the spinning required in the conventional spinner magnetometers. The cryogenic magnetometer requires only the movement of the sample into the measurement zone during the measurement and so it does not mechanically stress the samples appreciably. Ken Robertson, a fourth

year undergraduate will do the first study supervised by G.W. Pearce and J. Westgate. In the future we hope to examine other Southern Ontario deposits and deposits from other parts of Canada.

Paleomagnetism of Modern Lime Muds - Investigators: E. Craig Jowett and G.W. Pearce.

Since much work is now in progress at the University of Toronto on the paleomagnetism of limestones, Craig Jowett and G.W. Pearce have begun a study of the magnetic remanence of modern equivalents. We collected samples of lime muds from the Florida Keys by excavating them and leaving them to air dry without disorientation prior to transporting them to the laboratory in a μ-metal box. They were found to possess stable NRM intensities of about 10^{-7} emu/gm. AF demagnetization indicated that the remanence was single component. The direction at this remanence reproduced, within two degrees, the orientation of the present magnetic field at the sampling site. We are now comparing the characteristics of this remanence to those of ancient limestones and attempting to determine whether it is of a detrital or chemical nature.

Superconducting or Cryogenic Magnetometer - Investigators: Yeeming Wu and G.W. Pearce.

We are fortunate to have a unique cryogenic magnetometer manufactured by the Superconducting Technology Company. This magnetometer is probably the world's only magnetometer with ultra-high sensitivity (2×10^{-8} emu) and capable of taking samples as large as 4". Because of this unusual capability, it has also been necessary to develop the associated equipment required for the magnetic analysis of extra-large samples. Several sample holder assemblages have been constructed to take various sizes and shapes of sample. The largest sample holder can take samples with a maximum dimension of 3.5".

A demagnetization unit has been constructed, which includes a 10" cubic furnace for thermal demagnetization and an a.f. demagnetization system with a two-axes tumbling device. The furnace is capable of reaching 700°C in two hours, with automatic temperature regulating control to about 1°C. The whole demagnetization unit is kept in our μ-metal room. In order to carry out demagnetization in a zero-field environment, a 3 axis helmholtz coil has been set up around the edges of the μ-metal room. The residual field in the room can be kept below the 1 gamma range.

The electronic unit of the magnetometer has been modified to give a better filtering character, digital display and an extended dynamic range. The system has been calibrated directly against e.m.u. instead of the magnetic flux quantum (ϕ_o). It was found that the magnetometer had a serious magnetic flux leakage through its superconducting shield. Because of this, the 60 cycle magnetic noise in the laboratory was high enough to cause instability in two of the three sensors. To solve this major problem, a μ-metal shield was designed to reduce the flux leakage into the system. All the three sensors are now stable in 1 ϕ_o range.

Paleomagnetism of Paleozoic Sedimentary Cores - Investigators: G.W. Pearce and S. Poplawski.

Determination of the polar wandering curve for North America for the Paleozoic, particularly the early Paleozoic, has been slow due to scarcity of suitable rock formations. In the past undeformed igneous rocks and red sedimentary rocks have been preferred for this work and such are not well represented in North America for the Paleozoic. Recently however, we have found that limestones, which are abundant, can be used effectively for this purpose.

In an earlier study a Princeton Applied Research spinner magnetometer was employed to measure the very weakly magnetized limestone samples. This method worked well but measurements were slow thus limiting the number of samples that could be examined. Now a cryogenic magnetometer is working at the Erindale Laboratory and it enables us to speed up measurement of very weak samples. The cryogenic magnetometer has the added advantages of not requiring rapid spinning of the sample during measurement and of accomodating large (up to about 3½" diameter) and irregularly shaped samples. The latter feature enables us to look at a large quantity of standard 3½" core samples, previously of no particular value for paleomagnetism. These are available from many localities and for many ages. The major drawback to their use is their lack of orientation in a horizontal plane. Thus in most cases the magnetic pole cannot be determined but only the paleolatitude of the site. If results can be obtained from only a few localities, these would only be useful for checking more completely determined data. However, if a large number of localities representing a great spread in geographic coverage (say from one end of Canada to the other for a single time period) give results, then a paleolatitude map can be compiled (magnetic dip uniquely determines magnetic latitude for a dipole source) and the pole position extrapolated.

This study is just beginning with measurements in progress of pieces of a core drilled into Ordovician sedimentary rock underlying Lake Erie.

Magnetic Studies on Ocean Crustal Material from near the Mid-Atlantic Ridge - Investigators: M.E. Bailey and D.J. Dunlop.

The recovery of deep oceanic crustal material has provided evidence confirming in a general way the main assumptions of the Vine and Mathews hypothesis of sea floor spreading. This study is concerned with resolving a number of serious difficulties involving the origin, direction and stability of the remanent magnetization (NRM) of submarine basalts.

Large discrepancies between inclinations of the NRM and those expected from plate reconstructions exist at many DSDP sites. The best explanation of anomalously low inclinations at two sites close to the Mid-Atlantic is that a slow reversal of the earth's magnetic polarity has been recorded. Samples have been obtained from these sites and provide a unique opportunity for studying variations in the earth's field intensity during a reversal. Paleointensities are determined using the Thellier stepwise heating technique which presents a number of practical difficulties particularly for these deep ocean basalts. The freshest material is most likely to retain some or all of the original thermal remanence (TRM) but it is subject to physical and chemical changes on heating. Changes can occur at 200°C at which temperatures paleointensity values may appear artificially low because of viscous demagnetization of the NRM. Viscous properties of DSDP samples are being measured to determine the role of viscous processes and their importance (relative to chemical and physical variations) in explaining intensity fluctuations. Alternate methods which require no heating (such as anhysteritic remanence and normalization methods) are being used to determine fluctuations in the relative paleointensities during a reversal.

These methods assume that all or part of the NRM is thermal in origin. However, the NRM is usually partially a chemical remanence resulting from progressive magnemetization (low temperature oxidation of titanomagnetites) away from the ridge. The chemical remanence appears to remember the direction of the original TRM. Strong interactions between oxidised and unoxidised grains or regions may explain the memory property. Interaction fields can be examined by generating Preisach diagrams.

This study will also look at grain size variations with depth and distance from the ridge to determine the contribution of such effects on intensity fluctuations.

Multi-Component Magnetization Studies in the Grenville Province - Investigators: K.L. Buchan and D.J. Dunlop.

Detailed paleomagnetic and rock magnetic studies of metamorphosed basic intrusions from the Grenville Province are being continued with the investigation of the Thanet gabbro complex of Hastings-Haliburton region. Two stable magnetic remanences have been resolved - one using alternating field demagnetization, the other by thermal cleaning techniques. They have directions similar to the Grenville A and Grenville B directions isolated in earlier studies of the nearby Haliburton intrusions and by workers in other Grenville bodies. Grenville A directions are often considered to be older than B directions, largely because A blocking temperatures are consistently higher than B blocking temperatures. In the case of Thanet rocks, however, the blocking temperature spectra are reversed - B blocking temperatures are higher than A blocking temperatures. Obviously, simple thermal overprinting models to explain relative acquisition times of superimposed components must be discarded. Techniques to discover the chemical, thermal or viscous nature and, hence, the relative age of superimposed components are badly needed.

The Thanet and Haliburton multi-component studies provide excellent opportunities for the development of techniques to (a) separate superimposed magnetizations and (b) establish their origin. Separation techniques being investigated include vector subtraction, intersection of great circles, bulk mineral separations and combinations of alternating field and thermal demagnetization. The thermal, chemical or viscous origin of each remanence is being examined by viscosity experiments, thermal demagnetization of natural and thermoremanent magnetization, Thellier-Thellier paleointensity studies, petrological examination and a variety of further rock magnetic experiments.

Origin and Nature of Secondary Paleomagnetic Remanences - Investigators: L.D. Schutts and D.J. Dunlop.

Current research revolves around an investigation of the origin and nature of secondary paleomagnetic remanences. Rock magnetic theory and laboratory remanence measurements are being used to study metamorphic suites from southern Arizona and eastern Ontario. In the Tortilla Mountain region of Arizona, the Laramide age Sonora Diorite has intruded Late Precambrian diabase sills. In the Kirkland Lake region of Ontario, the 2.7 b.y. Matachewan dikes have been cut, in places, by 2.1 b.y. Abitibi dikes. Plans call for testing Arizona diabase and Matachewan samples taken at intervals away from the intrusive contacts. Thermally induced viscous remanence and chemical alteration of both contact and possibly regional metamorphic origin will be investigated as causes of secondary remanence.

(h) University of Western Ontario

DSDP Leg 37 Basalts (Carmichael) - Additional studies on the basalts from layer two just west of the mid-Atlantic ridge at 36°N have been conducted in an attempt to use anhysteretic remanence as a means of determining relative values of the paleointensity of the field. Values of ARM/NRM ratios even within a single flow are so variable as to suggest that ARM paleointensity methods are not applicable to these submarine basalts.

ARM/TRM ratios from recent lavas (Carmichael) - To use anhysteretic remanent magnetization RRM methods for paleointensity, the value of the

ARM/TRM ratio must be known. In the hope of determining this ratio for basalts, measurements of it were made using samples of the 1963-67 flows on Surtsey and the 1971 flow on Mt. Etna for which the magnitude of the field in which they cooled is known. Samples used had previously given acceptable values of paleointensity by thermal methods. The measured ARM/TRM ratios varied from 1.6 to 7.4 and 3.5 to 4.3 for the Surtsey and Etna samples respectively. The variability of this ratio suggests that ARM paleointensity methods are not reliable for these lavas.

Anomalously magnetized dike (Katigema, Palmer and Carmichael) - A dike near Sudbury, known from previous paleomagnetic studies to be anomalously magnetized, was extensively sampled and a close-spaced ground magnetometer survey was conducted over it. Some of the samples have an NRM that is as great as 60% of their saturation remanence. It seems probable that the dike has suffered repeated lightning strikes that have partially or completely remagnetized an appreciably part of its surface exposure.

Diabase Dikes Southwest of Sudbury (Palmer, Merz and Hayatsu) - The whole rock K-Ar age data and whole rock major element and trace element data collected by Merz and Hayatsu have been combined with the paleomagnetic data collected by Palmer on the Sudbury dikes of the Southern Province-Grenville Front region. These studies (reported on last year) have been integrated into a single manuscript which has been submitted for publication.

Paleomagnetism of Jurassic and Cretaceous Rocks from Chile (Palmer, Hayatsu and MacDonald) - Fold tests performed on the AF cleaned directions of remanence in these rocks indicate that the directions recovered are largely primary. However the results from a few sites appear to degrade the overall fold test presumably because of hard secondary (post-tilting) components. Thermal demagnetization studies have been begun in an effort to isolate pre and post tilt components. Whole-rock K-Ar studies are underway in an effort to determine more precisely the stratigraphic distribution of the Cretaceous volcanic rocks.

Keweenawan Conglomerate Tests (Palmer and H.C. Halls, U of T) - An additional 65 pebble samples were obtained from a conglomerate layer within the Keweenawan section at Mamainse Point. Because the local dip and strike is quite different from that on the Keweenawan Peninsula, this new collection will enable us to state whether the secondary component of magnetization (reported in more detail under University of Toronto paleomagnetism projects) was acquired prior to or subsequent to tectonic tilting.

Catfish Creek-Water laid Till Deposits at Plum Point, Ontario (MacGrain and Palmer) - A 5 meter section of this till deposit was sampled for a paleomagnetic study by Linda MacGrain. A far sided paleomagnetic pole (127°E, 77°N) was obtained from this section. The complete results of this study are reported in an unpublished B.Sc. thesis.

(i) University of Windsor

Papers related to the investigations listed are shown in the Bibliography under the names given here.

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

(1) Studies were confined to rock units along the Grenville-Superior boundary near Temagami, Ontario, to examine for metamorphic components.

(2) This study of rocks in the Kitimat-Prince Rupert area of the Coast Ranges is essentially completed. Two papers have been submitted

describing this work showing that the remanence is stable and primary, having survived a large scale fold test and tilting on fault blocks.

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

(1) Paleomagnetism of the Huronian Firstbrook Formation. Stratigraphic study of this unit shows the presence of three normal and two reversed zones which are stable to above 650°C. The results set limitations on Precambrian secular variation and on the 2.5-2.0 b.y. polar path arguments.

(2) Analysis of AF demagnetization data into the components using least squares methods.

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

(1) Paleomagnetic studies of Late Wisconsin tills. Studies were continued on till units along the east shore of Lake Huron.

(2) Characterization of tills using magnetic susceptibility. Studies were directed towards defining standard techniques for magnetic susceptibility measurements in tills.

8. Magnetosphere Studies

(a) Earth Physics Branch

Auroral Currents - A computer code was developed to simultaneously fit meridian chain magnetic observations and rocket or satellite based magnetic measurements to an electrojet and Birkeland current models. The VB-33 (Jan. 15, 1972) spin probe observations of Dr. J. Koehler and A. Sil were used together with the Churchill line of observation to construct a detailed auroral current mode. Intense, oppositely flowing electrojets were required to fit the combined observations, meridian currents were linked by equally intense Birkeland field-aligned currents. (J.K. Walker)

Cleft Currents - Model cleft current systems were constructed for post noon rocket events on 25th and 28th Nov. 1975 from electric field and ionosphere observations. The electric fields were determined from electrostatic analyser measurements (Daly and Whalen, NRC) and barium motions (Pongratz, LASL). The resulting electrojets were similar but higher than auroral electrojets and also flowing in opposite directions. Birkeland currents, which were calculated from divergent-free meridian currents, flowed outward at the observed locations of several arcs. (J.K. Walker)

(b) University of Alberta

Solar Terrestrial Interactions - The major new undertaking of the Space Physics group is the operation of a magnetometer array in western Canada for the International Magnetospheric Study. The array is in the form of a cross with the long axis along meridian 300°E geomagnetic from 60.6°N to 70.3°N and the short arm along latitude 67.3°N geomagnetic from 29°E to 3°E. The eight observatories include both magnetometers and riometers, and were set in operation during August. The array is under the management of Dr. D.W. Oldenburg.

In collaboration with Y. Kamide (NOAA, Boulder, Colorado) and S.-I. Akasufu (University of Alaska), Dr. Rostoker has studied the flow of Birkeland sheet currents in the morning sector using TRIAD polar orbiter data and ground-based meridian line magnetometer data. They find the Birkeland current sheets flow into and out of the electrojet region, and

they find evidence that the inward flow in the poleward region of the electrojet is stronger than the outward flow in the equatorward region.

J.V. Olson and G. Rostoker have continued their studies of pi 2 micropulsations, and have found strong evidence that these micropulsations cannot be thought of as simple eigenoscillations of magnetic lines of force. They find that the spectral components of pi 2's in the source region do not have a period-latitude dependence consistent with the eigenoscillation theory, and they propose resonant oscillations of the substorm current system as the source of pi 2's.

Dr. Olson has continued his studies of the relationship of pc 3, 4 micropulsations with the direction of the interplanetary magnetic field in collaboration with E.W. Greenstadt of TRW Laboratories (Los Angeles, California). Examination of Pc3, 4 micropulsation waveforms recorded at Calgary, Alberta show a tendency for signal enhancement to occur when the interplanetary field as measured by Explorer 35 magnetometers makes a small angle with the sun-earth line. This result is compatible with the suggestion that changes in the magnetosheath wave content produced by the changing bow shock configuration may be communicated to the surface of the earth.

K. Kawasaki and G. Rostoker, in collaboration with J.D. Winningham (University of Texas at Dallas) have initiated a study of the character of energetic particle precipitation across the auroral electrojets. They are paying close attention to the positions of borders of particle precipitation and electrojet borders, with a view to understanding the configuration of energetic particles and electric fields in the magnetotail.

D.W. Oldenburg has concluded a study of the limitations in inferring ionospheric current structure from ground-based magnetometer data. Using Backus-Gilbert inversion theory, he has successfully modelled data from polar magnetic substorms using the three dimensional current system developed by Kisabeth in the Space Physics group some years back.

H.-L. Lam has concluded his study of pc 5 micropulsations in the morning sector and giant 'pc 4' pulsations. He finds that pc 5 pulsations result from a combination of spatial oscillations and intensity oscillations of the westward electrojet in the morning sector. The sense of polarization of the pulsations is determined by induction effects in the earth and displacement currents in the F-region of the ionosphere. The 'pc 4' giant pulsations do not appear to occur in the electrojet region and are thought to be associated with true resonances of field lines. The 'pc 4' region of disturbance is highly localized in longitude, with phase changes of 180° occurring over distances as small as 5°.

T.J. Hughes is continuing his studies of current flow in the magnetosphere and ionosphere associated with steady state convection in the magnetosphere. He has developed a model current system which is consistent with all known observations of magnetospheric and ionospheric current flow, and is presently carrying out detailed model studies as well as investigating the mechanisms for generating the overall current flow distribution in the magnetosphere.

9. Lunar and Planetary Magnetism

(a) University of Toronto

Magnetic Paleointensities determined from Lunar and Meteorite Samples - Investigators: D.W. Strangway, G.W. Pearce, M. Lanoix, G.N. Hoye and Y.M. Wu.

The focus of this study is to use lunar samples and meteorites to determine the strength of the magnetic field present during the early history of the solar system. We are using the classic Thellier technique for this study but have found it difficult to heat samples to 780°C, the Curie point of iron, without altering the nature of the iron carrying the magnetization. Studies to control these changes using known oxygen fugacities are under way. At the same time, we have discovered that, where there are intergrowths of two magnetic phases, strong interactions and partial self-reversals take place making it difficult to apply the Thellier method. These interactions occur for example in intergrowths of iron and troilite in lunar samples. At the same time a similar interaction has been found in meteorites.

The question of how lunar samples became magnetized is also being examined by a study of micromagnetics. In this study a breccia is being taken apart grain by grain to see if the sample is homogeneously magnetized. The degree of thermal overprinting will then be established in cooperation with Ar^{39} isotopic studies. These results were presented at the 7th Lunar Science Conference and at the Western AGU meeting.

Models of Lunar and Planetary Evolution - Investigators: D.W. Strangway and H.N. Sharpe.

The new constraints on planetary conditions found as a result of the last few years of space exploration have opened up many new ideas on the evolution of planets. We have proposed a model for the evolution of the Moon that fits with all known observations. This model has been used to establish parameters of the formation condition of planets and the parameters derived have been used to model the evolution of all the terrestrial planets (including earth) and asteroids. These models all involve an early cool interior and warm exterior and then we model the changes with time due to various mechanisms of heat transfer in solid and fluid states and as a function of different radioactive contents. A special attempt has been made to include an explanation for the magnetic fields now found on several planets. These results were presented at the 7th Lunar Science Conference and at a Conference on Comparisons between Moon and Mercury.

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IV(B) AERONOMY

Compiled by: Dr. G.F. Lyon
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1. University of Alberta - Institute of Earth and Planetary Physics

(a) Solar Terrestrial Interactions

The major new undertaking of the Space Physics group is the operation of a magnetometer array in western Canada for the International Magnetospheric Study. The array is in the form of a cross with the long axis along meridian 300°E geomagnetic from 60.6°N to 70.3°N and the short arm along latitude 67.3°N geomagnetic from 292°E to 304°E. The eight observatories include both magnetometers and riometers, and were set in operation during August. The array is under the management of Dr. D.W. Oldenburg.

During the last year, Dr. R.P. Sharma left the group to pursue studies in computing science at the University of Toronto. Mr. R.G. Wiens obtained his M.Sc. and is presently employed as a computer analyst with the Government of Alberta. Dr. H.-L. Lam received his Ph.D. and is joining the Geomagnetism Division of the Department of Energy, Mines and Resources as a post doctoral fellow. During September Dr. Jerry L. Kisabeth joined the group as a Research Associate, while Dr. Koji Kawasaki was appointed Visiting Assistant Professor in the Department of Physics.

The main effort of the group continues to be devoted to the study of the solar terrestrial interaction using the magnetic signatures of the current flow in the magnetosphere and ionosphere.

G. Rostoker has continued to develop a model of the entry of solar wind plasma into the magnetosphere and the formation of the plasma sheet. He finds that hydrodynamic forces play an important role in establishing convective flow within the magnetosphere, while magnetic forces develop to modify the flow pattern producing a convective system sensitive to both the interplanetary magnetic field and the pressure of magnetosheath plasma normal to the magnetopause.

In collaboration with Y. Kamide (NOAA, Boulder, Colorado) and S.-I. Akasufu (University of Alaska), Dr. Rostoker has studied the flow of Birkeland sheet currents in the morning sector using TRIAD polar orbiter data and ground-based meridian line magnetometer data. They find the

Birkeland current sheets flow into and out of the electrojet region, and they find evidence that the inward flow in the poleward region of the electrojet is stronger than the outward flow in the equatorward region.

J.V. Olson and G. Rostoker have continued their studies of pi 2 micropulsations, and have found strong evidence that these micropulsations cannot be thought of as simple eigenoscillations of magnetic lines of force. They find that the spectral components of pi 2's in the source region do not have a period-latitude dependence consistent with the eigenoscillation theory, and they propose resonant oscillations of the substorm current system as the source of pi 2's.

Dr. Olson has continued his studies of the relationship of Pc 3, 4 micropulsations with the direction of the interplanetary magnetic field in collaboration with E.W. Greenstadt of TRW Laboratories (Los Angeles, California). Examination of Pc 3, 4 micropulsation waveforms recorded at Calgary, Alberta show a tendency for signal enhancement to occur when the interplanetary field as measured by Explorer 35 magnetometers makes a small angle with the sun-earth line. This result is compatible with the suggestion that changes in the magnetosheath wave content produced by the changing bow shock configuration may be communicated to the surface of the earth.

K. Kawasaki and G. Rostoker, in collaboration with J.D. Winningham (University of Texas at Dallas) have initiated a study of the character of energetic particle precipitation across the auroral electrojets. They are paying close attention to the positions of borders of particle precipitation and electrojet borders, with a view to understanding the configuration of energetic particles and electric fields in the magnetotail.

D.W. Oldenburg has concluded a study of the limitations in inferring ionospheric current structure from ground-based magnetometer data. Using Backus-Gilbert inversion theory, he has successfully modelled data from polar magnetic substorms using the three dimensional current system developed by Kisabeth in the Space Physics group some years back.

R.P. Sharma and G. Rostoker have continued their study of the so-called solar-weather effect, using a considerably larger data suite including surface pressures from several northern Canadian sites as well as polar zonal indices. They find that the correlation, if any, between tropospheric weather and the solar sector structure and/or magnetic storms is hidden below the noise level. They find that the superposed epoch analysis is subject to idiosyncrasies for small data samples which make it suspect as an analytical tool under certain circumstances.

H.-L. Lam has concluded his study of Pc 5 micropulsations in the morning sector and giant 'Pc 4' pulsations. He finds that Pc 5 pulsations result from a combination of spatial oscillations and intensity oscillations of the westward electrojet in the morning sector. The sense of polarization of the pulsations is determined by induction effects in the earth and displacement currents in the F-region of the ionosphere. The 'Pc 4' giant pulsations do not appear to occur in the electrojet region and are thought to be associated with true resonances of field lines. The 'Pc 4' region of disturbance is highly localized in longitude, with phase changes of 180^{o} occurring over distances as small as 5^{o}.

T.J. Hughes is continuing his studies of current flow in the magnetosphere and ionosphere associated with steady state convection in the magnetosphere. He has developed a model current system which is consistent with all known observations of magnetospheric and ionospheric current flow, and is presently carrying out detailed model studies as well

as investigating the mechanisms for generating the overall current flow distribution in the magnetosphere.

2. University of British Columbia - Dept. of Geophysics and Astronomy

(a) Recent IMS activities (T. Watanabe)

In cooperation with research teams from Univ. of Tokyo, Japan and Univ. of Victoria, B.C., we carried out continuous observation of magnetic pulsations during a period from Aug. 22 to Sept. 24 of this year at five locations in Manitoba; Star Lake (east of Winnipeg), Island Lake, Thompson, Gillam and Fort Churchill. At Thompson and Fort Churchill, the Univ. of Tokyo team (Prof. T. Oguti, Dr. K. Tsuruda and Dr. K. Hayashi) performed observation of aurorae and natural VLF radio emissions. At each of the two locations, a TV camera system and VLF receiver system with direction finding facilities were used. These systems were designed by the Univ. of Tokyo team. For observation of magnetic pulsations, 3 component induction magnetometer which was designed and built at UBC was used at each of the five stations. At Star Lake, an induction magnetometer system of Dr. R.E. Horita, Univ. of Victoria was also operated for a short time. This system employs one of the best amplifiers available commercially, and was expected to be able to doublecheck performance of the UBC induction magnetometer systems which use rather inexpensive amplifiers.

The pulsation data from the five stations came back to UBC two weeks ago. So far, we could only take a quick scan of the obtained data. However, it was found that the UBC induction magnetometer systems worked well. At Star Lake, the amplifier's main power supply unit failed to work occasionally, in a later stage of the operation. Except this period at Star Lake, a good quality of continuous data was obtained at each station.

The obtained pulsation data enables us to attack the following problems:

- Propagation mechanism of hm whistlers and emissions.
- Latitudinal distribution of IPDP activities.
- Origin of continuous irregular pulsations (Pi C) associated with on-off switching aurorae.
- Irregular pulsations associated with a break up phase of an aurora (Pi 2).

Comparison of auroral, VLF and pulsation data is expected to yield information on their mutual relationships over a considerable geographical extent. Some preliminary findings were already made, listed as follows:

- The area of a pulsating aurora is likely to be identical to the source region of auroral chorus emissions and of magnetic pulsations (Pi C).
- Daytime chorus emission is not directly related to magnetic pulsations.

3. University of Calgary - Department of Physics

Auroral Phenomena

Transition region (Cogger). This is an investigation of the relationship between the equatorward edge of the aurora and other known phenomena: plasmapause, mid latitude trough, plasma sheet electrons, ring current.

ISIS - Atmospheric Explorer comparisons (Anger). During a period last December when the ISIS orbit plane was aligned with that of AE(D) a number of

coincident passes were obtained during times when there were good viewing conditions. Analysis of the data is in progress.

Auroral patches and detached arcs near the plasmapause (Moshupi).

Auroral oval phenomenology (Murphree).

Aurora, total energy input (Harrison).

Pulsating aurora (Wallis).

Polar cap aurora (Cogger). We are studying the observed auroral features in the polar caps, including sun-aligned arcs and background aurora, and hope to relate these to magnetospheric behaviour.

Dayside aurora (Cogger). Although we have a limited data base, our observations indicate the existence of distinct auroral characteristics corresponding to the geomagnetic local time. The noon sector is of most interest because of possible implications for the magnetospheric cleft.

Ionospheric Phenomena

Midlatitude airglow (Cogger and Khaneja). We have identified characteristic midlatitude enhancements in the E region 5577Å emission. These enhancements which are largest in the winter hemisphere are being applied to the theories of thermospheric circulation.

Polar cap ionospheric currents (Wallis).

Comparison of auroral currents, particles and optical emissions in a quiet nightside aurora (Wallis).

ISIS-Chatanika comparisons (Anger). During December, 1975 a number of passes were scheduled over the Chatanika incoherent radar at times when auroral electric fields were being measured. Data analysis is in progress.

Night time ionosphere above Arecibo (Cogger). We are continuing to combine photometer, spectrometer, interferometer, incoherent scatter, and Faraday rotation data collected at Arecibo. Of present interest is the NI 5200Å emission and the F region 5577Å emission.

Atmospheric and Surface Phenomena

Ring effect observations (Barmore). Detailed investigations of effect in day sky with emphasis on polarization (if any). Re-examination of diurnal variation in light of possible polarization.

Ring effect instrumentation (Harrison). Implementation of a new ITT Vidissector tube for higher resolution study of Fraunhofer line filling-in. Possible extension to PDP11 control of electronic scanning.

Lightning observations from ISIS-2 (Wallis).

Albedo effects in aurora (Harrison). Utilization of a powerful albedo subtraction programme for making corrections to ISIS observations of aurora, leading to possible empirical approach for large scale auroral observation in ISIS-2 data.

Radiation cooling (Walton). Currently considering the feasibility of utilizing the atmospheric window region 8-14μ to produce cooling of real surfaces in the natural environment.

Atmospheric transmission, visual range (Harrison and Walton). Construction of a nephelometer is in progress. Plans to measure the integrated scattering coefficient for local air, will be extended to cover spectral measurements and relation to air quality and visual range.

Balloon Measurements of Cosmic Ray Electrons (C.J. Bland)

An experiment to measure the flux and energy spectrum of cosmic ray electrons was launched in a 6 m.cu.ft. balloon from Churchill, Manitoba, in July 1976. The twenty hour flight was terminated in the neighbourhood of Uranium City, N.W.T. Data were recorded throughout the flight and the instrument was recovered in good condition. This is the first occasion on which the flight services were supplied by a Canadian organization, SED Ltd., of Saskatoon. Data are now being analysed.

Cosmic Ray Modulation (C.J. Bland)

A theory to account for large Forbush decreases in terms of the modification of an essentially two dimensional diffusion process by the introduction of a loss mechanism in the third dimension has been studied. It is concluded that this mechanism which is presumably associated with interplanetary shocks could explain the time dependent intensity profile accompanying their passage. Good agreement with data from cosmic ray neutron monitor records has been obtained.

Infrared Astronomy and Submillimetre Stratospheric Studies

(a) Near IR Solar Observations - (D.A. Burrell and T.A. Clark)

Near IR observations of the sun between 3 and 5 μm using a simple rapid-scanning Michelson interferometer to obtain spectra every ½ second have produced exciting evidence of 5 minute intensity fluctuations which can be separated into solar CO absorption line variations and continuum fluctuations. Phase relationships between intensities at various wavelengths are being examined to provide parameters of solar surface-waves and their height dependence.

(b) Far-Infrared Stratospheric Absorption and Solar Studies - (D.A. Naylor, R.T. Boreiko and T.A. Clark)

The successful performance of the steering system on the University of Calgary balloon-borne solar telescope on the 1975 test flight (which steered to within the design specification of ± 8 arc minutes from the solar disc centre), and subsequent improvements led to a second successful flight in August 1976. Much improved performance and flexibility was obtained by the provision of automatic sensor gain control, sensor position adjustment by command from the ground and improvements in sensor characteristics. These led to ± 1 arc minute angular deviation of the optical beam from the solar centre throughout most of the flight and allowed the scanning of the telescope across the solar disc.

This telescope, equipped with a high resolution far-infrared Michelson interferometer, is being used for stratospheric absorption measurements and provides the high angular resolution necessary for the evaluation of the precise layer structure of minor stratospheric species during sunrise and sunset periods. Data obtained during a sunset on the August 1976 flight is now being analysed for this purpose.

(c) Submillimetre Stratospheric Emission Spectroscopy - (D.J.W. Kendall and T.A. Clark)

A Michelson interferometer, equipped to measure stratospheric far-infrared emission spectra, has been developed over the past three

years and in various designs has flown on six AES Stratoprobes and two U. of C. balloon flights in 1974, 1975 and 1976. The flights in 1976 provided good data for sunrise, sunset and limb scans of the Earth's high atmosphere which are being analysed to provide concentrations of such minor constituents as O_3, H_2O, $HC\ell$, HNO_3, NO_2 in the stratosphere.

Solar Terrestrial Relations

(a) Multi-Balloon Observations of Auroral X-Rays

The project of the multi-balloon study of Auroral X-Rays in conjunction with a comparison of satellite and ground observations in the Auroral Zone, has proceeded further. During the summer of 1975, about 21 balloons were launched by the Max Planck Institut, Lindau, from Kiruna and Lycksele in Sweden, while the University of Calgary launched 5 balloons from Great Whale River, Quebec. There are occasions when observations were available from three to four balloons at the same time. With the visits of Dr. K.K. Vij and Mr. Ken Deane to the Max Planck Institut and the subsequent return visit of Dr. J.W. Munch under a Canada Council Exchange Fellowship, further progress has been made, particularly in connection with the study of the data relating to June 30, 1975. Comparisons with charged particle data from the satellites ATS-6 and NOAA-4 has also been attempted. Further work is going on. A paper containing some preliminary results was also presented at the DASP meeting held at Calgary during February 19-20, 1976.

(b) IMS Project I

It is proposed to launch balloon-borne detectors from Cold Lake in conjunction with ground-based observations of Auroral Pulsations by Drs. F.T. Berkey and N.R. Parsons who will use their closed circuit image intensifier TV system. This will enable us to understand correlated changes in the low and high energy ends of the spectra. Balloon packages have been built as well as the telemetry command cut-down outfit developed and tested. The launches are planned for March/April, 1977.

(c) Rocket Observation of Auroral X-Rays

An engineering flight was successfully carried out in May from Fort Churchill. The attempt is to carry an Auroral X-Ray detector to an altitude of 60-65 km and eject it and then let it float down under paracute making measurements at various altitudes above those attained by balloons. The earlier engineering flight problem of a malfunction in the opening of the parachute system has been resolved by Bristol and plans are made for two rocket launches in February, 1977. The rocket payloads are under consideration.

(d) Study of the Solar Particle Event of November 18, 1968

This project, involving Dr. G. Wibberenz, University of Kiel, West Germany, Dr. L.J. Lanzerotti, Bell Laboratories, Murray Hill, New Jersey and D. Venkatesan, University of Calgary, has been completed. A paper has been accepted by the Journal of Geophysical Research for publication.

(e) Galactic Cosmic Rays

The study of the intensity variation of Galactic Cosmic Rays as observed by ground-based neutron monitors with particular emphasis on the daily variation and its relationship to interplanetary magnetic field fluctuations measured on spacecraft is nearing completion. A paper is almost ready for submission for publication. The collaborating scientists are Dr. J.W. Sari, Calspan, Buffalo, New York, Dr. L.J. Lanzerotti, Bell Laboratories and Dr. D. Venkatesan, University of Calgary.

(f) Study of the Magnetospheric Mantle - (D. Venkatesan, K.K. Vij, K.F. Deane and J.C. Barichello)

A study has been initiated in collaboration with Dr. S.M. Krimigis, Applied Physics Laboratory/Johns Hopkins University, Laurel, Maryland, to look at the magnetospheric mantle using the IMP satellite data.

(g) X-Ray Astronomy - (D. Venkatesan and C.M. Galas)

The collaboration with the Tata Institute of Fundamental Research, Bombay for the study of high energy Cosmic X-Rays has progressed further. The flight launch is scheduled from Hyderabad, India on November 30, 1976. The oriented balloon platform will carry a CsI-NaI phoswich detector with low background and of an area of 250 sq. cm. It is proposed to look at the Her X-2 source.

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

Magnetic Stations (J.K. Walker)

The Churchill line of magnetic stations was upgraded with low powered digital tape data loggers by October, 1976 from the Scratch chart recorders, which are now used as standby units. The line was straightened by moving the Norway House unit to Island Lake and an east-west auroral line was established with station at Ft. Severn and Thompson. Pelly Bay, which is just inside the cleft, was also established this summer. Zenith photometers are located at three of the stations, but unfortunately no new riometers could be obtained. This chain of stations is in both the magnetic and geographic meridians and is ideal for ordering observations from polar orbiting satellites, meridian launched rockets and meridian scanning photometers and radars. The data from these stations and from Mould Bay, which is also to be equipped with a low powered digital tape data logger by December, will be deposited in the WDC-A in digital form only. Funds and manpower are not available to plot the data. A list of magnetic stations and other known equipment on the Churchill array follows at the end of this section.

A cooperative program with Dr. Potemera of John Hopkins Applied Physics Laboratory resulted in satellite tracking facilities at Resolute for the TRIAD satellite. The station can track the satellite over the polar cap and across the cleft and auroral zones down to just south of Churchill. This magnetic data from the satellite complements the meridian chain magnetic data.

Auroral Currents

A computer code was developed to simultaneously fit meridian chain magnetic observations and rocket or satellite based magnetic measurements to an electrojet and Birkeland current models. The VB-33 (Jan. 15, 1972) spin probe observations of Dr. J. Koehler and A. Sil were used together with the Churchill line of observation to construct a detailed auroral current model. Intense, oppositely flowing electrojets were required to fit the combined observations, meridian currents were linked by equally intense Birkeland field-aligned currents.

Cleft Currents

Model cleft current systems were constructed for post noon rocket events on 25th and 28th Nov. 1975 from electric field and ionosphere observations. The electric fields were determined from electrostatic analyser measurements (Daly and Whalen, NRC) and barium motions (Pontgratz, LASL). The resulting electrojets were similar but higher than auroral electrojets and also flowing in opposite directions. Birkeland currents, which were calculated from divergent-free meridian currents, flowed outward at the observed locations of several arcs.

The Churchill Array (early 1977)

Station	Symbol	Equipment+ (Recorder*)	Geographic Lat.	Geographic Long. E	Geomagnetic Lat.	Geomagnetic Long. E
Alert	AT	V(A)	82.50	297.50	85.9	168.2
Resolute Bay	RB	O(A,D,T), I,(A), RI(A), PR(A,D), 1L	74.70	265.10	83.1	287.7
Pelly Bay	OB	V(A,D,S)	68.53	270.49	78.6	320.45
Baker Lake	BL	O(A,D,T)	64.33	263.97	73.9	314.8
Rankin Inlet	RI	V(A,D,S)	62.63	268.08	72.9	321.9
Eskimo Point	EP	V(A,D,S)	61.10	265.93	71.1	321.8
Ft. Churchill	CHR	O(A,D,T), I(A), R(A,D), RI(A), AS, PR(A), 5L	58.8	265.90	68.8	322.5
Back	BK	V(D,S), P(D)	57.69	265.77	67.8	323.0
Great Whale River**	GW	O(A,D,T), AS	55.27	282.22	66.8	347.2
Ft. Severn**	SV	V(D)	55.98	272.35	66.8	333.0
Gillam**	GM	V(A,D,S,), P(D)	56.35	265.32	66.2	323.4
Thompson**	TX	V(A,D), R(A,D)	55.72	262.12	65.4	319.3
Island Lake	IL	V(A,D,S)	53.88	265.32	64.0	324.4
Kenora	KEN	I(A)	49.80	265.60	60.0	326.4
White Shell	WS	O(A,D,T)	49.75	264.75	59.9	325.3

**East-west chain
+O = Magnetic Observatory
V = Magnetic Variometer
RI = Riometer
AS = All Sky camera
I = Ionosonde
R = Auroral radar
PR = Partial Reflection Ionosonde
P = Zenith Photometer
L = Rocket Launchers
*A = Analogue Recorder
*D = Digital Tape Recorder
*T = Telephone Telemetry
*S = Satellite Telemetry

5. Environment Canada - Atmospheric Environment Service

Experimental and Theoretical Studies (W.F.J. Evans, J.B. Kerr, J.R. Latimer, C.T. McElroy, R.S. O'Brien, R.A. Olafson, C.L. Mateer, G.M. Shah, R.K.R. Vupputuri and D.I. Wardle)

Experimental and theoretical studies of the stratosphere are continuing in the Atmospheric Processes Research Branch, in order to assess the effects that anthropogenic pollutants such as freons, SST's, and nitrogen fertilizers have on the ozone layer.

Results of the STRATOPROBE II balloon flights which were flown from Yorkton, Saskatchewan in August, 1975 have been analyzed. The vertical profiles of nitric oxide, nitrogen dioxide, and nitric acid were found to be much the same as the profiles measured during STRATOPROBE I from Churchill in July, 1974. Measurements of freon and N_2O were obtained from the stratospheric air samples taken during the 1975 campaign. The measured values of nitrogen compounds from STRATOPROBE I and II and the freon measurements of STRATOPROBE II are in good agreement with the nitrogen and freon photochemistry schemes assumed in stratospheric pollution models.

In 1976, two flights of STRATOPROBE III were flown from Yorkton in August. The payload configuration was similar to that of the chlorine configuration of 1975, the only changes being the replacement of the GASPEC by the scanning NO_2 spectrometer and the addition of a UV flux meter to measure the absolute solar flux between 190 nm and 210 nm. Remote sensing measurements of ClO and HCl may have been achieved.

Ground-based measurements of NO_2 and total ozone were carried out at Yorkton during the STRATOPROBE III operation. The NO_2 measurements were made with a spectrophotometer which is basically the same as the NO_2 balloon spectrophotometer. The ground ozone measurements were made with a Dobson ozone spectrophotometer which was stationed at Yorkton especially for the balloon campaign.

Daily surface-based measurements of total atmospheric ozone, made with the Dobson ozone spectrophotometer, continue at Churchill, Edmonton, Goose, Resolute and Toronto. The vertical ozone profile from the earth's surface to about 30 km is measured by balloon sounding with the Brewer-Mast electrochemical sonde each Wednesday at the first four of the above noted stations.

Observational testing and development of the new ozone network spectrophotometer is continuing. The new instrument is being compared with the Dobson instrument and the performance of the new instrument is being evaluated. A contract has been awarded to an industrial company for the development of a commercial version of the new instrument.

Numerical experiments were carried out incorporating oxygen-hydrogen-nitrogen-chlorine chemistry in a two-dimensional radiative-photochemical-transport model to investigate the possible potential effects of man-made sources of chlorofluoromethanes (freons) on the stratospheric ozone balance and its climate. The meridional stratospheric distributions of ozone, HO_X, N_2O, NO_X, CF_2Cl_2, $CFCl_3$, Cl_X, temperature and mean circulation were computed simultaneously for summer and winter seasons and the global depletion of total ozone due to the introduction of chlorofluoromethanes and their dissociation of products was assessed under steady state conditions. Additional experiments are now under way using the time dependent approach to the freon-ozone problem. This approach allows modelling of the time evolution of the distributions of above trace gases and of the global ozone depletion under varying conditions of freon injection rates into the atmosphere.

6. National Research Council of Canada - Communications Research Centre, Ottawa

ISIS Group

(a) Ionospheric Modification at Arecibo

Data from the July 1976 ionospheric modification experiment at Arecibo indicate that the Langmuir waves, responsible for the enhanced plasma line due to the HF heater, exist at a height a few kilometers above that predicted by theory. The height at which they exist is very close to the reflection height of the HF wave. It appears that the HF heater produces an electron density depletion in a small height range near reflection which allows the Langmuir waves generated by parametric decay to refract to where they can be detected.

(b) Ionization Ducts - (D.B. Muldrew)

A statistical study of the occurrence of magnetospheric ionization ducts, using Alouette II data, shows that ducts begin forming shortly after sunset centered on an L value of 1.4. After midnight an additional source of ducts appears at an L of about 1.1 (F region near the equator).

Shortly after sunrise the ducts at lower L values disappear and the number at higher L values decreases. From about noon until sunset, the duct distribution remains constant with none below L = 1.4 and from L = 1.4 to 2.0 the number density is about 20% of the night time value.

(c) Intersatellite Radio Propagation

The intersatellite radio propagation study using the ISIS I and II sounders continues to yield interesting data. Two papers are being written, one about the upper branch electromagnetic propagation modes, and another dealing with the peculiarities of the whistler mode. We are able to make some conclusions about the wave-vector spectrum radiated by the dipole antennas and about the role of high latitude irregularities in scattering whistler-mode waves. We have obtained intersatellite wave propagation data in other physically interesting situations, such as at frequencies near a mode cutoff and near an electrostatic resonance, (the kind that gives a spike on the ionogram). In addition the intersatellite data confirm that the sounder transmitter can generate propagating electromagnetic waves nonlinearly: O-mode waves have been observed at frequencies differing from the transmitter frequency by the local gyrofrequency.

(d) Z-Mode Radio Noise

Recent observations by other satellites of low- and medium-frequency terrestrial radiation in near space has rekindled interest in auroral wave processes. In this context we are studying a band of MF noise observed by the ISIS I and II sounder receivers near the auroral oval. The dependence of the noise spectrum on point of observation is analyzed by using simultaneous data from the two spacecraft. As well, evidence about its directional properties and about its correlation with energetic particle precipitation is brought to bear. The noise bandwidth characteristically lies above the local plasma frequency and below the gyrofrequency, and since there are no electrostatic wave models in this frequency domain, the implication is that the observed signals originated in another region. Conceivably this CMA-6 noise is one intermediate stage of noise which eventually, by reflections and scattering couples into the O-mode and escapes upward from the magnetosphere. The present study is limited to an attempt to characterize the noise and understand its generation, and to thus provide background information that may be useful for understanding terrestrial radiation into space.

(e) Future Plans (H.G. James)

Current activities have been organized bearing in mind that DOC research on ISIS may soon be reduced to zero. Consequently we have restricted our studies to ones that promise fast, fast, fast results. Prospective ISIS users within DASP and elesewhere requiring data of a type not yet collected would do well to consider their modes and discuss them soon with the ISIS group, especially if these involve the ISIS radio experiments.

(f) Theoretical Study

The numerical time-dependent model of the F-layer and topside ionosphere, described in the last newsletter, has been finished, and a paper describing the results has been submitted to Planet. Space Science.

(g) Winter Polar Ionosphere (J.H. Witteker)

Work is nearly complete on a study of the quiet winter polar ionosphere during two successive ISIS I and ISIS II nearly-coincident passes. That is, there are two "snapshots" of the ionosphere, taken about

2 hours apart, each snapshot involving two satellites (as well as some data obtained on the ground). At, and prior to, the time of the first snapshot, at 0530 on December 14, 1971, the magnetic disturbances were very slight, while the second pass occurs during a substorm. The optical data for this pass show a westward travelling surge.

The main results of the winter polar ionosphere study are as follows:

- In the topside light ions are much more abundant in relation to oxygen ions than in the sunlit polar ionosphere. They are, however, less abundant in the polar cap (open field lines) than in the auroral belt (where they are, in turn, less abundant than in the plasmasphere).

- A rule of thumb seems to be that the topside ionosphere is significantly disturbed where the soft electron precipitation is intense enough to excite >1 kR of red-line emission, as seen from above.

- Even in the dark winter polar ionosphere, where precipitation is obviously important in influencing the density of the F layer, horizontal drift is nevertheless also very important. Thus the F layer in the polar cap is controlled by the drift pattern during relatively inactive periods, because the polar cap precipitation at such times is usually weak.

- The occurrence of a substorm, at least in this instance, was associated with ionospheric changes. The pockets of low density in the F layer were filled in and smoothed over after the substorm activity, and this effect is apparently due to a change in the pattern of magnetospheric convection. In the topside, the boundary of light ions moved equatorward as a result of the substorm, and became sharper.

7. National Research Council - Herzberg Institute of Astrophysics

Planetary Sciences Section

(a) Auroral Spectra and Photometry (R.L. Gattinger and A. Vallance Jones)

The 9000 - 11000 $\mathring{A}$ region spectra obtained over the past two winters have been reduced and compared with synthetic spectra; the results are now in press in CJP.

A new $H\beta$ meridian scanner using 3 inch filters is being constructed. This photometer which will have 12 inch Cassegrain collecting optics will be controlled by a microprocessor. A microprocessor will also be used to format the digital output on the tape.

(b) Radio Aurora (D.R. McDiarmid and A.G. McNamara)

In the past year, a study of the errors one encounters in the measurement of the aspect sensitivity of radio aurora was completed. It was shown that the errors arising in the determination of the aspect angles are as important as the errors arising in the determination of the backscatter cross-section. The former have not been adequately assessed in most of the published measurements.

Studies of high latitude day side radio aurora are proceeding satisfactorily. The relationship of this radio aurora to the position of the cleft, to the regions under field-aligned current flow and to the position of ionospheric electrojets is being investigated. The radio aurora is the diffuse type and appears similar to that seen in the evening.

The auroral radar network is being renovated and upgraded for use during the I.M.S. period.

(c) Cosmic Dust Studies (R. Wlochowicz)

The analysis of the particles collected by the balloon-borne experiment (Magellan) is not yielding conclusive results. On the basis of collection rates with time, the results of the third flight disagreed with the trend apparent in the first two. An explanation based solely on the shedding of contaminants from the collection funnel would attribute improbable properties to the funnel. A more likely source of contamination is the balloon itself, which, though located 1000 feet above the funnel, could, during extremely still conditions in the atmosphere, drop particles into the funnel below. It appears that the experiment should preferably be flown during conditions of light sheer winds than during the turn-around periods selected for our three flights. The chemical composition of the collected particles varies over a wide range and no particle with unquestionable signs of ablation has been found which would tie any particular chemical composition to an extraterrestrial origin.

Several hundred particles from the rocket collection have been scanned for chemical composition. One apparent difference has been found between the larger particles which could be lifted from the collecting surfaces and the smaller ones which could not. The latter showed a high titanium component. In the next flight, collections will be made directly onto carbon surfaces so that all chemical analyses will be made against the same background material.

(d) Meteor Research (B.A. McIntosh, I. Halliday and P.M. Millman)

Routine recording of meteors was continued at Springhill Meteor Observatory and at Shiels Meteor Station in the cooperative program with Dudley Observatory (Albany, N.Y.) and Smithsonian Astrophysical Observatory (Cambridge, Mass.). Observations made with a sensitive closed-link T.V. system are combined with those of our normal grating spectrographs, the Super-Schmidt camera, and two backscatter radars.

An exceptionally bright fireball was observed visually and by radar at Springhill and with the spectrographic cameras at Shiels on November 6, 1975 and reductions are in progress. The radar echo shows a duration in excess of 10 seconds and at a terminal height near 36 km this represents the lowest atmospheric height ever recorded by a meteor radar.

The Quadrantid meteor shower on the night of January 3/4, 1976 was observed from a NASA Lear jet flying above the clouds in the vicinity of Springhill. More than 100 meteor spectra were recorded with two vidicon spectrographs on the aircraft and the results are being combined with the radar records from Springhill and some visual observations from the aircraft. The project was undertaken because of the favourable conditions of longitude and moonlight in 1976 and involved cooperation among the NASA Ames Research Center, the Harvard-Smithsonian Center for Astrophysics, the Dudley Observatory and the Herzberg Institute of Astrophysics.

Study of possible excess angular momentum carried into the Earth's atmosphere was extended by an analysis of the meteors in the McCrosky-Posen catalogue of Super-Schmidt photographed meteors. Corrected mean angular momentum is approximately unity as expected but the necessary weighting factors to correct for observational selection are sufficiently uncertain that any calculated value is of low accuracy.

Research in cooperation with meteor scientists in Czechoslovakia led to the completion of an analysis of meteor heights determined from the decay rates of meteor echoes recorded on the Ottawa 3-megawatt radar. In another study the low-power Patrol records were used to show that the echo duration from large, low-velocity meteors depends on whether the atmosphere

is sunlit or not. Electron removal processes which contribute to echo decay are stronger at night than in the daytime.

(e) Infrasound from Meteors (B.A. McIntosh, M.D. Watson and D.O. ReVelle)

An array of 4 infrasound detectors has been in operation near Saskatoon since late summer of 1975 in an attempt to record low-frequency pressure waves generated by large meteors. An analog recorder was added to the system in mid-1976 to facilitate the selection of promising records from the digital data for detailed processing. As yet no signals have been identified unequivocally as being of meteoritic origin.

The similar, higher-frequency array at Springhill Meteor Observatory, near Ottawa, is being modified (late 1976) to provide digital data recording under the control of a microprocessor. A parallel analog record will be maintained as at the Saskatoon installation.

A study of the dynamics and thermodynamics of meteorite ablation has been completed. The model utilizes simple, "classical" ablation theory but allows an incrementally varying ablation coefficient depending on altitude, meteor velocity and body size. At low altitudes, radiation heating is several times greater than convective heating. Predictions of the model compare favorably with the well documented meteorite falls - Lost City, and Pribram.

(f) Meteorite Recovery (A.T. Blackwell, A.A. Griffin and I. Halliday)

The meteorite camera network in western Canada has continued in normal operation. A very bright meteor observed on December 16, 1975 from the only two stations not yet closed down because of morning twilight is of considerable interest. Although the initial velocity was higher than that normally associated with a meteorite fall, this object penetrated the atmosphere and decelerated to a velocity such that a small meteorite fall may have occurred. A search of the ice on a large lake in western Saskatchewan shortly after the event and again before spring breakup yielded no meteorite fragments.

A stone meteorite found near Blaine Lake, Sask. and weighing about 2 kg was identified by the MORP office in Saskatoon and later acquired for the National Meteorite Collection.

Space Physics Section

(a) Auroral Particle Studies

Instruments designed to measure the energetic and thermal charged particle distribution functions were carried on six sounding rockets launched during the winter and spring of 1975-76. Two instrument packages were flown from the Cape Parry, (N.W.T.) range in November 1975 as a part of operation Periquito which was a joint Los Alamos Scientific Laboratories-NRC experiment involving shaped charge barium releases and ambient charged particle measurements in the magnetospheric "cleft".

Two experiments designed to measure the charged particle distributions in the nightside aurora were carried on NRC sponsored rockets launched from Churchill Research Range in January and February 1976.

A Herzberg Institute of Astrophysics charged particle sensor package was also carried on a NASA-University of Texas at Dallas rocket launched in March 1976 from the Churchill Research Range.

The last experiment in the program was carried on a Los Alamos Scientific Laboratories sponsored STRYPI IV rocket which as launched in

June 1976 from the Kauai test range. This experiment involved the measurement of ionospheric perturbations induced by the explosive release of a large quantity of barium (~ 7 times the quantity released in previous experiments).

Data obtained from these flights are at present being analysed in cooperation with scientists from the other groups involved.

(b) Magnetospheric Studies

Data from the Energetic Particle Detector and the magnetometer on ISIS-2 are being used to carry out various magnetospheric studies.

A comparison has been carried out between the Mead-Fairfield magnetic field model and ISIS particle measurements. The analysis involves the determination of the latitude at which, on the average, electron energies are a minimum and the identification of this latitude with the average position of the high-latitude limit of closed field lines. At local noon the closed field line limit as given by the model is in good agreement with the measurements except for large negative values of the tilt angle of the earth's axis, and here the measured tilt angle dependence is smaller than is predicted by the model. However, the measurements show a significant dependence of the latitude of the last closed field line on local time, which the model does not allow for.

Studies involving the first simultaneous measurements of field aligned currents and charged particles by a low altitude polar orbiting satellite have been carried out. Some of the conclusions reached from these studies are the following:

- The region of field aligned currents causing the magnetic perturbations is approximately coincident with precipitating electron fluxes in the auroral oval.

- Precipitating electrons in the energy range ~0.1 to ~1 keV carry the upward current in the cleft. They correspond to oval aligned arcs in the cleft.

- The fluxes of precipitating protons are insufficient to carry the downward current. It is presumably carried by ionospheric electrons with energy $\leq$5 keV.

- During geomagnetic storms, magnetospheric protons (~5-150 keV) and plasma sheet electrons precipitate adjacent to the cleft in a sunward convecting region at MLT as early as 13-15 h.

- Cleft fluxes also occur partly in the sunward convecting region and partly poleward of it.

- Most of the magnetic perturbations are modelled best by equal and opposite field aligned currents joined in the ionosphere by Pedersen currents at the same MLT. From this one can infer gross ionospheric electric field directions and convection directions.

(c) Cosmic Ray Studies

The NRC Space Physics group continued to operate cosmic ray monitor stations at Deep River, Alert, Inuvik, Goose Bay and Ottawa.

In February, 1976, the second quarter of the near-horizontal muon detector array was brought into operation. In September, 1976, about one month's work remains to complete the array.

Cosmic ray electron, proton and alpha particle intensities in the interplanetary medium have been analysed to compare the solar modulation of these species in the years 1965-1972. Whereas the regression curve between the intensities of relativistic protons and alphas of the same rigidity shows no appreciable hysteresis, a striking hysteresis effect exists in the corresponding case of protons and electrons. This difference between protons and alphas on the one hand, and electrons on the other is difficult to explain using conventional modulation models, wherein modulation processes depend only on particle rigidity. It is thought that this effect is a manifestation of the gradient-curvature drift of the particles in the interplanetary magnetic field which depends on the sign of the particle charge.

Space Research Facilities Branch (J.F. Aitken)

The Space Research Facilities Branch has scheduled ten rocket launches from the Churchill Research Range during the period January to March 1977, in support of Canadian scientists. Seven rocket launches are scheduled during the period February to March 1977, in support of scientists from US agencies. One scientific balloon launch is scheduled for the period February to March from Cold Lake, Alberta.

One of the rocket launches scheduled for Churchill during the month of February will be the inaugural scientific flight of the Nike Black Brant VB rocket system. Two Nike Black Brant rockets are scheduled for launch from Cape Parry, Northwest Territories during the period November to December 1977.

The Canadian Scientific Balloon Launching Facility, which was established by SRFB in cooperation with the Atmospheric Environment Service, was inaugurated in July and August 1976, with one flight from Churchill, Manitoba and four flights from Yorkton, Saskatchewan. The Churchill flight carried a cosmic ray telescope and all of the Yorkton launches carried stratospheric constituent experiments.

SRFB is currently studying the path of the 1979 solar eclipse, with a view to selecting rocket and balloon launch sites to support scientific investigations of the eclipse.

Rocket Schedule

Vehicle No.	Project Scientist	Area Under Investigation
ADD-VA-45	D.J. McEwan	Auroral Spectroscopy
AND-VB-44	H.P. Gush	Background Cosmic Radiation
AED-VB-46	J.H. DeLeeuw	Electron Beam Fluorescence
	B. Whalen	Measurement of Electrons and Ions
	P. Forsyth	Pulse Radar System
	B. Whalen	Energetic Particle Detector
	D. Venkatesan	X-Ray Detectors
ADD-VA-49	E.J. Llewellyn	Mesospheric Composition

Further details on the payloads and conditions may be obtained by writing to the named investigators in each case.

8. University of Saskatchewan

IMS Coordination (B.W. Currie)

A booklet, entitled "Canadian Based Activities, International Magnetospheric Study, 1976-1979", was circulated to those concerned with the

IMS in May 1976. The planned projects, while not as numerous or elaborate as many of us would have liked, are adequate to meet Canada's responsibilities with respect to the IMS. Some modifications and changes to proposed projects as described in the booklet are taking place as they are being brought into effect. The IMS experimenters are being informed of these by the newsletters which I send to them. Consideration is now being given to preparing a second edition of the booklet incorporating the changes and additions to the projects, - especially for international distribution to those who may want to use Canadian-based data in the analyses of their IMS data. Due to delays in launching key spacecraft, and the planning and equipping of some IMS campaigns, the most effective, collaborative period for the IMS is likely to be late 1977 and all of 1978. A request has been made to the International Council of Scientific Unions for a one-year extension to the IMS, and I anticipate that this request will be approved. In any event, essential data from magnetometer lines and spacecraft are likely to be available throughout 1978 and 1979 to complement data acquired by ground-based campaigns.

IMS Project

During the past 8 years, measurements based on partial radiowave reflections (see above) have been influenced, both positively and negatively, by the production of ionization due to high energy (up to ~500 keV) electrons precipitating at our location (L = 4.4). Though electron precipitation has been studied from ground by optical and riometer techniques, it appears that a study via partial reflection techniques has something to offer. Thus as an IMS project, special recordings of the ratio of polarized waves reflected at 2.2 MHz have been instigated, to provide data for longer-term studies of this phenomenon. Since a single radiowave frequency is inadequate for this purpose, arrangements are in hand for the construction of a broad-band, log-periodic, polarized antenna, plus additional electronic equipment to transmit and receive pulsed signals. A multi-channel scanning photometer (D.J. McEwan), and the partial reflection winds system, are being used in conjunction with this new system. This will allow temporal and spatial variations in airglow and aurora to be related to ionization and atmospheric motions (winds and waves) under quiet and disturbed conditions.

Ionospheric Electric Field (J.A. Koehler)

The flight of rocket VB-39 from Ft. Churchill provided some exciting data. A periodic variation in both the measured electric field and in the ion motions was observed. Although data analysis is not complete, the observations are compatible with a horizontal, transverse wave with a wavelength of the order of km. This data was presented to the DASP symposium in Calgary and is in press with the Journal of Geophysical Research.

A remote, microprocessor-controlled data collecting station was installed at Cree Lake, Sask. The instrument records the outputs of a three-axis magnetometer, two photometers (5577Å and 3914Å), a microbarometer and an anemometer on digital magnetic tape.

Dynamical Studies of the Mesosphere and Lower Thermosphere (J.B. Gregory, A.H. Manson, D.G. Stephenson and C.E. Meek)

Measurements and analyses of winds data, obtained from a partial reflection radiowave system by means of the drifts technique, have been continued. It has been possible to assess the relative importance of gravity, planetary and tidal waves, as perturbations to the mean flow in the altitude range 60-110 km. The major stratospheric warming of December 1974 - January 1975, has been studied by means of daily measurements of the mean wind, and cross correlations and spectral analyses have revealed the presence of associated planetary waves to altitudes of at least 100 km. The data will be published soon and comprise a unique set of data of value to theorists. Coupling events between the stratosphere-ionosphere-magnetosphere at mid-

latitudes in the southern hemisphere, for the years 1969-74, have also been assessed by one of us (A.H. Manson, sabbatical leave). This study, together with a long-term study by colleagues in New Zealand, have confirmed the occurrence and importance of such events. It was also shown that magnetic activity was directly or indirectly involved in determining the magnitude of the ionospheric response.

The capability of the experimental system for intensive soundings (12 profiles/hr) has been further exploited in studies of tides and gravity waves. Estimates of the amplitudes, vertical and horizontal wavelengths, and periods of gravity waves have been obtained; it has also been shown that the momentum deposition into the background flow leads to significant accelerations, that the heating due to dissipaton is comparable to solar radiation at certain heights, and that eddy diffusion coefficients due to the waves are comparable with independently measured estimates. For the first time, spectral analysis techniques have been used to show the coherence of gravity wave modes (20-120 minutes) within the mesosphere and stratosphere; data obtained by one of us in Adelaide (A.H. Manson) also indicates the importance of gravity waves at this low latitude.

Comparisons of winds data, and of techniques of analysis, between workers at CRC (Ottawa), the Physics Department, University of Adelaide, and the Institute of Space and Atmospheric Studies (ISAS), have led to a better understanding of the usefulness of variants of the analysis technique, which has been used since the early 1950's. In particular, internal consistency techniques have been developed to determine the reliability and usefulness of wind estimates; and significant improvements in the observational efficiency of the analysis have resulted from making better use of the capabilities of digital computers. These techniques will enable researchers at a variety of geographical locations to optimize certain parameters of experimental systems, and also help them to select the most effective variant of the winds analysis technique for their location.

Infrared Studies (E.J. Llewellyn, J.L. Corr, B. Solheim, S.R. Lim and B. Long)

During the last year the analysis of data from rocket and balloon flights has continued and it is now possible to provide new information concerning ozone distributions at high latitude. The experiments conducted from Kiruna, Sweden, during twilight at the end of the Arctic winter provided a complete determination of the ozone height profile from the ground to 100 km. The actual measurements coincided with the final winter warming and indicated a decreased ozone concentration in the 85 km region. The measured concentration was similar to that observed during the summer months at 52°N. It has been shown from a comparison with model calculations that the measurements are consistent with an increased water vapor concentration and an enhanced eddy diffusion coefficient. This may indicate that large changes of the lower boundary eddy coefficient are consistent with changes in the stratospheric circulation which could be important in the estimation of residence times in the stratosphere.

Support for these conclusions has been obtained from a comparison of the extensive solar eclipse rocket observations with full model calculations. These latter have shown a reduction in the 75 km ozone concentration following totality, and its slow recovery, so that measurable effects still exist during the twilight following the eclipse. This appears to be significantly different from results obtained close to the equator where no change in the ozone concentration could be detected.

To extend the present synoptic observations of ozone height profiles using conventional balloon-sondes a new form of optical sonde is being developed and it is planned to undertake the first flight during the coming winter in

conjunction with a rocket firing from Churchill. The purpose of the latter is to provide a direct means of comparing the two methods.

The Michelson interferometer is now nearing the operational stage and will be used in field trials during the winter. The preliminary laboratory observation has shown that the system is operating to design specifications. To provide real time spectra it is intended to include a small microprocessor in the instrument; in this manner low resolution spectra will be available for immediate checking of the instrument and for use in the handling of the full data analysis.

Auroral investigations using side-look photometers are continuing and the initial data has suggested the existence of vibrational development in the 1PG bands of N_2. There also appears to be an extension of these emissions beyond the main visible auroral form; it is hoped that these observations will be confirmed with the forthcoming rocket flight ADD-VA-45.

To provide further information on chemical processes in the mesosphere a new rocket instrument has been developed to study odd-oxygen concentrations. As part of this investigation the radiative transfer of the oxygen atmospheric bands will also be studied.

Auroral Studies (D.J. McEwen)

D.J. McEwen is on sabbatical leave at the Appleton Laboratory, Slough and has been working with D.A. Bryant's rocket group. They are investigating auroral particle acceleration mechanisms and have a number of rockets scheduled for launch at Andoya in November. He will undertake some studies of pulsating aurora while at Andoya and also plans to visit Tromso and Kiruna observatories.

There are plans for further cleft region studies. Detailed analysis of the electron data from VB-41 showed acceleration of electrons from about 200 eV to 700 eV in a narrow region within the cleft, similar to inverted V structures seen in auroral forms in the night side. Photometric measurements will be attempted at Mould Bay ($\Lambda = 79^{\circ}$) in December 1977 using a 6 channel meridian scanner to study the morphology and structure of the cleft.

A 0.4 m spectrometer has been assembled to measure auroral emissions in the region 300-1250Å. It was scheduled for flight on VA-45 last winter (a reflight of the auroral payload of II-128) but some problems encountered in final assembly and check-out finally forced a postponement of the flight until 1977.

Solar UV Measurements

A ¼ meter spectrometer was again flown on the AES stratoprobe balloon program with two flights in August, 1976 from Yorkton. The solar spectra (1850-3100Å) obtained from the first balloon flight from Churchill in 1974 has been analyzed and the solar flux observed in the window region around 2100Å has been compared with the predicted flux at the balloon height.

Cybernetics Laboratory (K. Paulson, R. Schnor, L. Bérubé, R. Frehlich and M. Schmid)

CDAS-1

Hardware and software development of CDAS-1 (Computerized Data Acquisition System) is now complete. Based on a DCC-116 minicomputer with 32K of 16-bit-word core memory, CDAS-1 provides programmed data acquisition and instrument control for scientific observations. Data from a 16-channel, 12-bit, A/D converter (25 kHz throughput) and a digital port (9.6 kHz throughput) may be recorded (after optional preprocessing and detection) on a

45-ips, 9-track, magnetic tape unit. Timing is provided by a crystal-controlled real-time clock and simultaneous paper recordings may be made with an 8-channel D/A converter and chart recorder. Observing instruments may be placed under program control through an output digital port. A highly-versatile real-time operating system which incorporates the programming language BASIC is accessed by the user by means of a high-speed CRT terminal.

Co-ordinated Photometric Studies (R. Montalbetti and D.J. McEwen)

A six-channel scanning photometer has been operated under the control of CDAS-1 for short periods in July and November, 1976, in order to monitor auroral and night-sky emissions near Saskatoon. Five narrow-band spectral regions centered at 4278, 4861, 5577, 6300 and 6700 Angstroms plus one background wavelength may be monitored every 100 msec. Elevation angles may be changed in half-degree steps between any two preselected values. Auroral measurements with this photometer will be made from La Ronge during the dark phases of the moon in December, 1976, and February, 1977. The latter measurements will be co-ordinated with the photometric observations made at three other stations by Drs. A.V. Jones, F. Creutzberg, F.R. Harris and R.L. Gattinger of N.R.C. All data from this experiment will be recorded on magnetic tape in a digital format.

Observations of the Micropulsation Substorm

These observations will be made from stations near La Ronge, Saskatoon and Lucky Lake in conjunction with the photometric measurements described above. Both three-component induction coil and fluxgate magnetometers will be operated at each station. Maximum sensitivity of the induction coil magnetometers is 10 pT at 100 mHz. Data will be recorded on magnetic tape in a digital format.

Fluctuations in Auroral Brightness at 4278 and 5577 $\mathring{A}$

A method for relating the time variations in the brightness of these auroral emissions has been developed which treats the basic process as being deterministic. Random fluctuations are assumed to be the result of the probabilistic nature of the excitation, emission and detection (counting) processes. For data with a high signal-to-noise ratio, no statistically significant departures from the Omholt equation have been found. Lifetimes of the 1S state of atomic oxygen appear to be higher on the average for data recorded at Tromso than for data recorded at Saskatoon. It is planned to acquire more data of this kind during the expedition to La Ronge in February, 1977.

Auroral Backscatter Studies (G.J. Sofko)

(a) Doppler Spectra of 42 MHz CW Auroral Backscatter

During the past year, a Doppler system (Haldoupis et al., 1976) has been operated in which a 50W CW transmission is beamed northward from Saskatoon, and a 5W auxiliary transmission, locked to the 50W signal, is beamed westward to act as a reference signal at the receiving site, some 35 km away. The reference signal is shifted up 1562 Hz, and is then mixed with the scatter to produce an audio signal centered at 1562 Hz for recording on an analogue tapedeck. These audio recordings are then analyzed by a Hewlett-Packard Fourier Analyzer at the Controls Lab of the College of Engineering. Excellent spectra have been obtained, the usual analysis being a 2048-point sample taken in 0.41 ms, the frequency resolution being 2.44 Hz. Furthermore, there is always a slight leakage of the reference transmission on to the main receiving antennas, and this acts as a very valuable zero Doppler shift reference for the frequency spectrum.

The results of several complete nights of aurora have been published (C. Haldoupis and G. Sofko, 1976) indicating three main observations:

- very narrow spectra, less than 20 Hz in width and centered at +125 ± 15 Hz, are frequently observed, and appear to be caused by ion-acoustic waves;

- there is a regular variation of the mean Doppler velocity during the night, a crossover from south to north occurring about 3 a.m. CST, and this mean speed seems to be a good measure of the average east-west electric field causing Hall drifts in the north-south direction;

- when the crossover occurs (i.e. there is zero mean Doppler shift), the scatter disappears, so the same mechanism that produces the drift seems to be the cause of the irregularities themselves, implying their generation by the electric field.

Work is in progress at the moment on the relationship between the amplitude fading spectrum and the Doppler frequency spectrum.

A co-operative venture with Dr. J. Koehler is underway in which a microprocessor-controlled ground station has been out-fitted at Cree Lake by Dr. Koehler to make microbarograph, magnetometer, and photometer (3914Å, 5577Å) readings. Further stations are planned for Wollaston Lake and Lynn Lake. This would enable a detailed correlation to be made between the radio scatter, the optical fluctuations, and the current systems flowing. A forward scatter transmitter is being planned for installation at Baker Lake, its path midpoint also being over the area covered by the ground stations.

(b) Polarization Studies of 42 MHz Auroral Backscatter

A paper based on the M.Sc. thesis of N. Bedard has been accepted for publication in the Canadian Journal of Physics (Bedard and Sofko, to be published). The main observation is that the received scatter has the opposite orientation from that expected on the basis of Faraday rotation. This seems to indicate that the scattering process itself introduces both a phase anisotropy (π radians) and an amplitude anisotropy ($\rho_v/\rho_h \simeq 2$ to 4) between the vertical and horizontal components of the signal incident on the scatterers.

Theoretical work on the polarization changes expected from an assembly of anisotropic scatterers in a magnetoplasma is proceeding.

9. Simon Fraser University - X-Ray Astronomy (B.G. Wilson)

We have been involved in x-ray astronomy research dating back to 1964 which, until recently, has concentrated upon the cosmic x-ray diffuse background in the 2 - 10 keV region. Since 1970 emphasis has shifted to instrumentation development in order to extend measurement capability to lower energies and higher sensitivity resulting in the production of our multi-wire proportional counter system incorporating a novel method of gas pressure regulation, automatic counter gain control and ultra-thin x-ray windows. An initial flight of this system from Hawaii was not successful due to rupture of the counter window upon deployment of its protective door. The problem has been resolved and elaborate protective devices have since been incorporated into the counter system. In 1973, a rocket pointing device became available for Canadian experimenters for the first time and we have now developed a grazing incidence x-ray "lens" capable of exploring small angular diameter x-ray sources with good resolution. The combination of the "lens" with appropriately miniaturized proportional counters provides a 200-fold increase in angular resolution and an order of magnitude increase in sensitivity over our previous system. This new "telescope" has been developed during 1975 and

1976 and recently passed environmental tests. It is scheduled for launch in November 1976 from Woomera together with an ultra-violet experiment provided by Dr. Nicholls of York University.

The telescope will conduct a preliminary survey of two extragalactic objects - M31 in Andromeda and the Small Magellanic Cloud (SMC). These objects have been previously studied but with low angular resolution and sensitivity. We will attempt to observe the spatial distribution, intensity, and energy spectra in 0.1 - 2 keV and hopefully to detect absorption of a possible universal diffuse x-ray background. Sensitivity of the M31 measurement will be enhanced by the use of a rotating scan in which the elliptical object cyclically fills the rectangular instrument field of view, thus modulating the signal at a known frequency. This mode of observation must also be used for the SMC due to pointing system limitations, although a raster scan would be preferable for that object.

Upon recovery of the experimental package, it will be refurbished as necessary and reflown. Further refinement of our x-ray optics will be undertaken to suit the improved capabilities of new observational platforms which will likely be available in the near future. Observations of M31 will be strongly emphasized in subsequent flights. This object is important as a prototype for models of the Galaxy because of its similarity and proximity to our system.

10. University of Victoria - Department of Physics

Twilight Airglow (H.M. Sullivan)

Measurements of twilight airglow emissions from atomic lithium have continued at Victoria, employing a birefringent photometer. Vertical density distributions have been determined for enhanced emissions following rocket releases of lithium vapour into the upper atmosphere. Two rocket releases at Poker Flat, Alaska, on October 13, 1972, appeared to produce an enhancement at Victoria 2½ days later, the clouds having propagated to Victoria with a mean velocity of 10.5 m/sec. Somewhat smaller enhancements were observed about 4 days after rocket releases at Sondre Stromfjord, Greenland on December 17, 18, 1974, indicating a propagation velocity of about 13.5 m/sec. Calculations of the topside scale height were made; however, subsequent studies have suggested that the transmission function employed is not appropriate for twilight lithium studies, particularly if the layer is very thin.

Enhanced emissions were again observed following rocket releases of lithium vapour trails at Poker Flat on March 27, 28, 1976. Although the observed intensities were not as great as in 1972 there is little doubt that the enhancement was a direct result of the releases. The drift velocity of the cloud on this occasion was about 5.9 m/sec. The average height of maximum density for five of the best observations was 91.8 km.

Construction of a 1.5 m Ebert type scanning spectrometer is nearing completion. This instrument will be used primarily for photometer calibration purposes.

Some consideration is being given to studies of anomalous emissions in the EUV region of the auroral spectrum.

Plasma Waves (R.E. Horita)

Recent studies at the University of Victoria of ISIS VLF spectrograms kindly supplied by Drs. R.E. Barrington and F.H. Palmer of the Communications Research Centre, Ottawa, have resulted in the observation and analysis of fine structure at harmonics of the proton and/or helium gyrofrequency on whistlers, auroral hiss and ELF hiss. The observed proton or helium gyrofrequency is not necessarily the same as the local value in the immediate vicinity of the

satellite. An observed value larger or smaller than the local value indicates that fine structure modulation took place below or above the satellite respectively. For example, ELF hiss modulation observed inside and outside the plasmasphere indicates upward and downward wave propagation respectively, consistent with Poynting vector observations. Analyses of the fine structure modulation have yielded approximate locations for the modulation source regions. In the case of ELF hiss inside the plasmasphere, the modulation source region appears to lie along a magnetic field line near the equator related to the equatorial anomaly.

Theoretical work to complement the above experimental observations indicates the fine structure modulation can be obtained under certain plasma conditions. The theoretical work employs ISIS satellite data such as ion composition kindly supplied by Dr. J.H. Hoffman of the University of Texas at Dallas.

Studies of ISIS topside sounder ionograms are also continuing in an effort to find a theory for the origin of proton cyclotron echoes and spurs.

A study of micropulsations is also continuing in collaboration with Dr. T. Watanabe of the University of B.C. and Prof. T. Oguti of the University of Tokyo. In August and September, 1976, micropulsation data were recorded near Winnipeg, Island Lake, Gillam, Thompson and Churchill while data from the University of Tokyo VLF and auroral TV camera systems were obtained at Churchill and Thompson. In addition, ISIS I and II satellite experiments were turned on for satellite passes close to Winnipeg with the cooperation of Dr. H.G. James of the Communications Research Centre.

11. The University of Western Ontario - Centre for Radio Science, Department of Physics

Ionospheric Irregularities

The dual frequency of arrival system (150 and 400 MHz) operated at Cambridge Bay during a ten day period in Aug. 1975 (J.A. Fulford). The apparent movement of the magnetospheric cleft was tracked near local magnetic noon on consecutive days. As well ionospheric irregularities measured at 400 MHz gave scale sizes to .5 km and gradients along the motion of the line of sight of 4×10^{12} m^{-3} and peak electron concentrations of some 1.5×10^{12} in excess of background concentrations. Some results of this experiment were presented to the COSPAR working group on "The Geophysical Use of Satellite Beacon Observation" at Boston University in June and will be published in their proceedings.

This equipment was operated for a 13 day period in July 1976 at Cape Parry (J.A. Fulford) and a simultaneous set of measurements was carried out at Cambridge Bay (P.A. Forsyth) using the same frequencies. The Cambridge Bay system consisted of a short base line simple interferometer at 400 MHz and separated receivers (~0.5 km) at 150 MHz. Very preliminary results indicate good quality records from which it should be possible to measure heights of ionization irregularities along the line of sight to the satellite as well as some of the characteristics of the ionization as a function of height particularly in the magnetospheric cleft region.

Auroral Rocket Programme

The 108 MHz coherent pulse radar rocket packages are now complete. It is expected that two of these will be flown in BBVI rockets from Churchill in Jan. 1977. If these are successful later flights will be made in the polar cap and cleft regions (Forsyth).

Travelling Ionospheric Disturbances

A dual frequency (140, 360 MHz) differential angle of arrival system is now in place awaiting the return of the ATS 6 satellite which should come into view in October. It is intended to follow this vehicle until it reaches parking orbit at 135° East longitude. This is not such a favourable 'look' position as that originally planned and further observations will await preliminary results.

A new 7.35 MHz oblique doppler sounding system with improved frequency resolution has been in operation for some nine months and some success has been achieved in obtaining real time frequency spectra of the received signals (Lyon).

Meteor Studies

The meteor radiant determination programme has been highly successful and new methods have been tested using first monte-carlo methods and then visual meteor data which was kindly supplied by Dr. B.A. McIntosh at N.R.C. The final form of the analysis uses a technique of deconvolution of spherical harmonics and the computer codes, which are useful in other areas, are freely available on request.

As a result of the success with the radiant analysis of visual data we are proposing to extend the method to radio meteor observations and we have a design study underway for a suitable system.

The television meteor programme is proceeding well with the two station system. The rate of doubly observed meteors is about 15-20 per clear night of observing. The heights of these meteors can usually be measured to an accuracy of better than 300 metres or so (Jones, Hawkes and Morton).

Scintillation Studies

Observations of the movement of scintillation (F region irregularity) patches have commenced with a view to deducing F region electric fields. An initial phase of this project has been the setting up of monitor stations to look at the occurrence patterns of the irregularities and to look for movement of large irregularity patches. Three such monitor stations at London, 18 km SE of London at Delaware Radio Observatory, and 80 km north of London at Blyth have been operating for 6 months on a routine basis using ATS 3 as the source. Construction of arrays for the measurement of movement is due to begin shortly (MacDougall).

Sq Current Systems Calculations

A new analysis technique called a 'separation' has been employed to show that the Sq current system is composed of three main components: (1) A component which shows up most clearly in the seasonal variations of the Sq system and which is probably due to semidiurnal winds. (2) A component of magnetospheric origin 'a la Matsushita' which is about ½ the overall system. (3) An 'isomorphic' component which shows little variation and could be due to direct ionospheric heat input.

Details of these will be published shortly (MacDougall).

Radio Auroral Spectra

A cooperative experiment with the Stanford Research Institute was carried out in February, 1976, using the Homer, Alaska 398 MHz phased-array radar to provide rapid-scan maps of radio auroral spectra. A maximum entropy method of spectral analysis has been used to estimate spectra from the raw time series. The first results obtained differ from previous observations in that spatial-

temporal ambiguities in doppler velocity have been considerably reduced by the rapid scans, revealing in some of the data very rapid temporal changes in the azimuthal variation of doppler velocity; the data also provide the first extensive UHF doppler data from the morning sector. To date, most of the maps examined contain nearly constant doppler velocities over the entire 40^{o} of azimuth scanned by the radar, except that on occasion there is an abrupt change from positive to negative velocities, reminiscent of type I echoes obtained from the equatorial electrojet. Some of these data also have double-peaked spectra, with each maximum located at approximately the ion-acoustic speed, but having different signs (Moorcroft).

12. York University - Centre for Research in Experimental Space Science (W.A. Gault, R.A. Koehler, R.N. Peterson, J.F. Pieau, F.W. Thirkettle, G.G. Shepherd and E. Stathopoulos)

ISIS-II Studies

Data continue to be received from the Red Line Photometer on the ISIS-II spacecraft, and it is expected that operation will continue through the IMS. Current efforts in the data processing involve a more complete library system for cataloguing passes, and better 6300 A intensity contour maps. E. Stathopoulos was successful in applying a Fourier image reconstruction technique in the inversion of SAR arc scans to volume emission rate contours. Much of the data bases for the University of Calgary Auroral Scanning Photometer have been merged with ours, and we will soon have the capability of simultaneous processing and merging of the University of Texas soft particle spectrometer data. The ISIS-II experiments continue to collaborate and meet at regular intervals about three times annually.

Topics of current study include the Aug. 4, 1972 SAR arc, the Dec. 14-21, 1971 storm and the magnetospheric cleft.

Rocket Studies

A 6300 $\mathring{A}$ photometer was flown on a Japanese K9M rocket from Uchinoura in January, 1976, into the predawn enhancement. Photoelectrons produced at the magnetic conjugate point were observed by Drs. Hirao and Mukkai with their photoelectron spectrometer, and the vertical profile of the 6300 $\mathring{A}$ emission is entirely consistent with excitation by photoelectron impact.

Dr. Ashley Deans completed his PhD thesis on the design, flight and analysis of the data from rocket AMD-VB-34, launched at Fort Churchill on Jan. 23, 1974. There were 56 optical channels employed, and together with Dr. McEwan's soft electron data, Dr. Zipf's mass spectrometer data, Dr. Evan's photometer data and Dr. Harris' photometer data, Dr. Deans was able to deduce: (1) the vertical profile of atomic oxygen composition ($1.7 \times 10^{11} cm^{-3}$ at 100 km) (2) the ratio of O_2 Atmospheric (0-0) band emission intensity to that of N_2^+ at 4278 A (an order to magnitude less than that inferred from ground based measurements) (3) that energy transfer from the $A^3\Sigma_4^+$ state of N_2 is an important mechanism for populating the ^1S state of O and hence producing the auroral green line (4) an expression for the quenching rate of N_2 $A^3\Sigma_4^+$ by O_2 (the rate is found to be temperature dependent). (5) rotational temperature versus height profiles; there is some evidence for a higher temperature from N_2^+ than from O_2.

IMS Project

An instrument shelter and mirror scanning system has been constructed for our dayside cleft expedition to Cambridge Bay, Nov. 20 - Dec. 18. A four channel interference filter photometer, with a Fabry-Perot etalon in the 6300 $\mathring{A}$ channel, and a scanning wide angle Michelson interferometer are being prepared for the trip, along with a digital data acquisition system. It is

hoped that 24 hr per day of meridian scan 6300 Å data will be obtained, and complete spectra through the visible region of the cleft emission.

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V ISOTOPE STUDIES AND GEOCHRONOLOGY

Compiled by: P.H. Reynolds

1. University of Alberta - Departments of Geology and Physics
2. Bedford Institute of Oceanography - Chemical Oceanography Division
3. University of British Columbia
   (a) Department of Geophysics and Astronomy
   (b) Department of Geological Sciences
4. Dalhousie University - Department of Geology
5. McGill University - Department of Geological Sciences
6. McMaster University - Department of Chemistry
   - Department of Geology
   - Department of Physics
7. Queen's University - Department of Geology
8. University of Toronto - Department of Physics
9. University of Western Ontario - Department of Geophysics
10. Bibliography

1. University of Alberta - Departments of Geology and Physics

Investigators: H. Baadsgaard, C. Banks, G. Bloy, G.L. Cumming, D. Davis, J. Gray, D. Krstič, R. Lambert, R.D. Morton, K. Muehlenbachs, S.J. Song, P. Thompson and S. Winzer.

U-Pb isotopic study of Rabbit Lake, Saskatchewan uranium deposit - Cumming with J. Rimsaite, Geol. Surv. Can.

Pb isotopic variation in Thompson Lake, Manitoba sulfides - Cumming with O.R. Eckstrand, Geol. Surv. Can.

Isotopic composition of Pb in Mexican and Central American Pb-Zn deposits - Cumming with S.E. Kessler, U. of Toronto.

Oxygen and hydrogen isotopic variation in tree rings: paleoclimatic implications - Gray, Thompson and Song.

Simultaneous O and H isotopic determination in H_2O and organic compounds - Gray and Thompson.

Re-determination of half life of ^{87}Rb from highly purified $RbClO_4$: initial ratios and chemistry - Gray, Cumming and Davis.

A detailed isotopic study of minerals from the Nûk gneiss, W. Greenland - Baadsgaard with V. McGregor and D. Bridgwater, Geol. Surv. Greenland.

U-Pb dating of zircons from the Malton Gneiss, B.C. - Baadsgaard and Lambert.

Geochronology of the Charlebois Lake area, Wollaston Lake Belt, Saskatchewan - Baadsgaard, Krstič and Cumming.

K-Ca and Rb-Sr dating of sylvite and carnallite from the Devonian evaporites in Saskatchewan - Baadsgaard with N. Wardlaw, U. of Calgary.

Geochronology of the Saglek Bay area rocks of Labrador. A long-term multi-method study with special reference to polymetamorphism - Baadsgaard with K. Collerson, Memorial U. Nfld. and D. Bridgwater, Geol. Surv. Greenland.

Detailed isotopic study of polymetamorphism in a segment of the Kootenay Arc, B.C. - Baadsgaard, Winzer and Muehlenbachs.

A radiometric study of the uranium mineralization in the area of the East Arm, Great Slave Lake, N.W.T. - Baadsgaard and Bloy.

K-Ar reconnaissance of the extent of a relatively undisturbed Archean terrain within the Hudsonian metamorphic province - Baadsgaard and Banks.

Geochronology of the PE shield area of N.E. Alberta - the batholitic terrain - Baadsgaard with J.D. Godfrey, Res. Council Alberta.

Oxygen isotope geochemistry of oceanic crustal materials recovered by IPOD and DSDP - Muehlenbachs.

Oxygen isotopic study of uranium ore deposits - Muehlenbachs and Morton.

Oxygen diffusion in silicates - Muehlenbachs.

Oxygen isotope variations in volcanic rocks from Western Canada - Muehlenbachs.

2. Bedford Institute of Oceanography - Chemical Oceanography Division

Investigators: F.C. Tan, A. Walton, P.M. Strain and J.N. Smith.

C^{13}/C^{12} studies of Red Sea Brines - A joint project was carried out with Dr. M. Schoell, Federal Institute of Geosciences and Natural Resources, Hannover, Federal Republic of Germany, on carbon isotope variations in total dissolved CO_2 from Red Sea Brine samples. The samples were collected during the "Valdivia" expedition to the Red Sea in 1972, and the mass spectrometer determinations were carried out at the B10 stable isotope laboratory. The purpose of the study was to investigate the genetic relationships among the various brine pools in he Red Sea (Atlantis 11, Discovery, Chain Deeps and others) based on C^{13}/C^{12} ratios and the concentration of the total dissolved CO_2. Our data indicate that the brines in Discovery and Chain Deeps are derived from the Atlantis 11 brines and that low C^{13}/C^{12} ratios (-20^{o}/oo PDB) and CO_2 concentrations (10 ~ 20 ml/l) observed in Discovery and Chain Deeps result from carbonate precipitation under closed system conditions.

C^{13}/C^{12} in total dissolved CO_2 in estuarine environment - Surface water samples were collected along the Upper St. Lawrence Estuary and the Saguenay Fjord during April, 1976. The samples were analyzed for their C^{13}/C^{12} ratios in the total dissolved CO_2 in order to examine the mixing behaviour of C^{13}/C^{12} ratios in fresh and saline water in an estuarine environment. The analytical aspect of this work has been completed, and the interpretation of the data is underway.

C^{13}/C^{12} studies in organic matter in estuarine sediments - Grab sediment samples from various locations in the Gulf of St. Lawrence, St. Lawrence Estuary and the Saguenay Fjord were analyzed for C^{13}/C^{12} ratios in the total organic carbon in order to study the contribution of land-derived organic matter to Gulf of St. Lawrence sediments. The extreme δC^{13}PDB values are recorded at the limits of the geographical area covered, i.e. from -29.4^{o}/oo at Quebec City and -26.6^{o}/oo at the head of the Saguenay Fjord to -21.6 in the Laurentian Channel southeast of Cabot Strait. A steady downstream increase in C^{13}/C^{12} ratios occurs in both the St. Lawrence Estuary and the Saguenay Fjord. Remarkably uniform values are observed in the open Gulf of St. Lawrence (-22.6 ± 0.7^{o}/oo) differing very little from those found on the Scotian Shelf and in the Laurentian Channel oustide Cabot Strait (-22.3 ± 0.8^{o}/oo). On the basis of these carbon isotope studies we conclude that terrestrial organic matter from the St. Lawrence River is deposited

within the Estuary and that the organic matter of the sediment in the open Gulf of St. Lawrence River is principally of local or marine origin.

These studies of C^{13}/C^{12} ratios in organic matter are being extended to suspended particulate material collected in the Gulf of St. Lawrence and to sediments from the Canadian Arctic Archipelago.

O^{18}/O^{16} ratios: the mixing of water masses - A detailed study of the mixing of fresh and saline waters in the St. Lawrence Estuary based on the O^{18}/O^{16} method has been performed. The data indicate that the range of O^{18}/O^{16} ratios varies linearly from the surface waters of the St. Lawrence River (-10.3^{o}/oo SMOW) throughout the Estuary to the saline waters of the Gulf of St. Lawrence (-2.0 /oo SMOW). O^{18}/O^{16} ratios are being used to calculate the mixing ratio of fresh and saline waters at selected stations and to estimate the O^{18}/O^{16} ratios of local meteoric waters.

The application of the O^{18}/O^{16} method to mixing of water masses is being extended to the Labrador Sea and waters of the Canadian Arctic Archipelago.

Pb^{210} sedimentation rate studies - Sedimentation studies are being carried out using the Pb^{210} method on samples collected in the Saguenay Fjord by the CSS Hudson in April 1976. The initial objective is to determine sedimentation rates in support of previous qualitative estimates based on the accumulation of Hg from anthropogenic sources. Samples are being dissolved and the Pb^{210} content measured via α spectrometric determination of the daughter product Po^{210}. Ra^{220} supported Pb^{210} is using the radon gas emanation technique.

Significant bioturbation is evident in some cores down to depths of 100 cm., and work is necessary to assess the effect on the Pb^{210} geochronology. Preliminary estimates suggest sedimentation rates of ~ 0.5 cm/yr.

3. University of British Columbia - Department of Geophysics and Astronomy

Investigators: R.D. Russell, W.F. Slawson, R.D. Meldrum, P. Shore and T.K. Ahern.

The Mass Spectrometer Laboratory of the Department of Geophysics and Astronomy houses three 12-inch mass spectrometers operated by this Department and an AEI MS10 operated by the Department of Geological Sciences. There are four small chemical laboratories for sample preparation and processing, as well as a laboratory used by the Department of Geological Sciences for potassium analyses for potassium-argon geochronology. Our laboratory co-operates very closely with Dr. R.L. Armstrong, Department of Geological Sciences. Much of the rubidium-strontium work has been transferred to Dr. Armstrong's laboratory, with our laboratory concentrating on the analysis of oxygen and lead.

During the year of this report, we continued to devote a considerable part of our energies to the much needed improvement of instrumentation. We have completed the design and construction of a new implementation of the thick-lens source designed in our laboratory six yers ago by A. Loveless. The new design is much superior mechanically and provides for much more reliable high voltage insulation. In addition, it was possible to realize more accurately the dimensions specified in the Loveless design. The result has been that the performance of the source approaches much more closely to the theoretical predictions.

Our mass spectrometers are operated by an Interdata mini-computer, on an interrupt-servicing basis. Overall control is maintained by the Interrupt Supervisor, for which the programming was written in our laboratory several years ago. This year we have re-written the software of the support routines for the mass spectrometer dedicated to lead isotope analyses. The new

supervisor provides for a much higher level of automization and a more effective use of mass spectrometer time.

A small theoretical study was completed by R.D. Russell and T.K. Ahern of the transients that may result in a gas-source sample line when changes occur in the flow rates, for example by the switching from sample to standard in a stable isotope machine. The calculations were made using a one-dimensional Green's function, and apply to the viscous flow regime. A manuscript has been submitted for publication.

Theoretical studies of the isotopic dilution analysis of strontium, described in an earlier report, have been extended. The results predict the possibility of infinite error magnification in the composition, in the case in which isotopic and composition information is acquired from a single mass spectrometer analysis. That this could happen has been recognized in the past by others writing on this topic, but the new formulation seems to give an improved understanding of the phenomenon and a simpler procedure for testing for the conditions of instability. A paper on this subject has been accepted for publication by Chemical Geology.

The studies of the oxygen isotopic changes in artificial tracing experiments on Mount Seymour, described in last years report, have now been completed. Problems of demonstrating the conservation of isotopic species which troubled us in the beginning have now been resolved, and an acceptable interpretation has been obtained. A paper by T.K. Ahern and R.D. Russell has been submitted for publication.

A major integration of isotopic data for the Omineca Crystalline Complex of British Columbia, by Blenkinsop and Birnie, with other geophysical and geological data, has been undertaken. A major metamorphism at 55 m.yr. ago, clearly recorded in K/Ar and Rb/Sr data, confuses the interpretation of the earlier chronology. However, indications of earlier events seem to be present. This work is a joint undertaking of R.D. Russell, J.V. Ross, J. Blenkinsop (now at Carleton University) and D.J. Birnie (now at Chevron Standard, Calgary).

M. Yamaguchi, W.F. Slawson and R.D. Russell have revised and somewhat extended the isotopic and isotope dilution analyses of lead from JOIDES Leg 37. The additional new data are primarily new chemical composition determinations for lead. A manuscript on this topic has been accepted by the Canadian Journal of Earth Sciences.

Department of Geological Sciences

Investigators: R.L. Armstrong, J.E. Harakal and K. Scott.

Projects currently underway are summarized below. Cordilleran projects are arranged in order of tectonic subdivision and are described first.

Insular Belt - Rb-Sr isochrons: Bonanza volcanics, Island Intrusions, Sicker Volcanics on Vancouver Island. K-Ar: Cenozoic Volcanics on Vancouver and Queen Charlotte Islands. Sr initial ratios on all volcanic and plutonic groups. (With J. Muller, G.S.C.; I. Young, U.B.C.)

Coast Mountains - Rb-Sr isochrons and fission track, K-Ar, and Rb-Sr mineral dates, Prince Rupert region. (With D. Runkle and M. Harrison, U.B.C.)

- Rb-Sr and K-Ar studies of Coast crystalline belt near Atlin Lake. (With T. Bultman, Yale; Werner, U.B.C.)

- K-Ar on young plutons, Sr initial ratios, southern Coast complex. (With G. Woodsworth, G.S.C.; N. Green, U.B.C.)

Cascade Mountains - High pressure metamorphism: K-Ar and Rb-Sr dating. (With N. Brown, W.W.S.C. and W.W.S.C. grad. students; P. Misch, U. Wash.) - Crystalline core-Skagit Gneiss and related rocks. (With P. Misch, U. Wash.)

Interior Intermontane Belt - Rb-Sr and K-Ar studies of the Hogem batholith. (With G. Woodsworth, G.S.C.; T. Eadie and J. Stock, U.B.C.)

- Rb-Sr isochrons and initial ratios for volcanic and plutonic suites of Paleozoic and Mesozoic age. (With J. Monger, G.S.C.; J. Grette, U.B.C.; T. Bultman, Yale; A. Panteleyev and V. Preto, B.C.D.O.M.)

- K-Ar dates for plutons near Oliver. (With P. Read, G.S.C.) Whitehorse plutonic belt (With C. Godwin, U.B.C.; G. Morrison, U.W.O.)

Omineca Belt - Rb-Sr isochrons for Yukon crystalline complex and Klotassin batholith. (With C. Godwin, U.B.C.; D. Tempelman-Kluit, G.S.C.)

- Rb-Sr and K-Ar studies of Wolverine Complex. (With R. Parrish, U.B.C.)

- Shuswap granitic rocks near Wells Gray. (With L. Pigage, U.B.C.)

- Shuswap gneisses near Kalamalka Lake. (With P. Solberg, U.B.C.)

- Shuswap gneisses in the Trinity Hills and gneisses near Oliver. (With W.H. Mathews, U.B.C.)

- Grand Forks gneisses in Ferry County, Washington. (With E. Cheney, U. Wash.)

Cenozoic Volcanics - Sr initial ratios for all major late Cenozoic volcanic centres in B.C. and Yukon. K-Ar dating. (With J. Souther, G.S.C.; M.L. Bevier, N. Green, B. Watters, W.R. Danner and W.H. Mathews, U.B.C.)

- Sr in ultramafic nodules from alkali basalts in B.C. (With R. Maxwell, U.B.C.)

Canadian Shield - Athabasca Sandstone and cross-cutting dikes: Rb-Sr isochrons. (With P. Ranamakers, Sask. Geol. Survey)

Miscellaneous Foreign Projects - Deccan basalt and spilite: Sr isotopic composition. (With K.V. Subarrae, Indian Inst. Technology.)

- Indian shield and crystalline basement on Main Central Thrust of Himalaya Mountains: Sr and K-Ar geochronometry. (With H.R. Wynne-Edwards, U.B.C.)

- K-Ar dates for Bitterroot Lobe of Idaho Batholith. (With L. Williams, U. Mont.)

- K-Ar and Sr isotope studies of Ixtaccihuatl Volcano, Mexico. (With G. Nixon, U.B.C.)

- K-Ar dating of Snake River Plain volcanic rocks. (With P. Williams and H. Prostka, U.S.G.S.)

- K-Ar dates, high pressure metamorphism of Sierra foothills. (With R. Schweikert, Lamont Geol. Obs.)

Geochronometry-Techniques - Rb-Sr dating of sphalerite. (With R. Maxwell, U.B.C.)

4. Dalhousie University - Department of Geology

Investigators: P.H. Reynolds, M. Zentilli, G.K. Muecke and V. Stukas.

$^{40}Ar/^{39}Ar$ Dating of Plagioclase Feldspars (Stukas and Reynolds) - Graduate student V. Stukas has recently completed a very detailed study of the apparent age spectra characteristic of plagioclases separated from various plutonic hypabyssal and volcanic regimes. The spectra are practically always 'disturbed' to a greater or a lesser degree. Nevertheless, valuable geochronological data can often be gleaned. Low to intermediate temperature data on samples from Atlantic Canada very frequently record Acadian overprinting at ≈370 m.y. ago. At high extraction temperatures, the argon released from a calcic phase appears to dominate the age spectrum. Age plateaus above ≈1050°C are frequently observed and do appear, in at least some instances, to give valid crystallization ages. Unfortunately, it appears that the existence of a high temperature plateau does not necessarily rule out the presence of excess radiogenic argon.

Dating of Fluid Inclusions in Ore Deposits with the $^{40}Ar/^{39}Ar$ Method (Zentilli and Reynolds) - Some fluid inclusions contain brines with measurable concentrations of potassium. The 40/39 technique possibly provides a way of 'opening' these 'containers' and counting the relative number of K and Ar atoms. The results to date are mildly encouraging in that we were able to obtain a date for some inclusions in quartz that agrees with the geological age of the associated ore deposit. Such studies will be pursued in 1977.

Dating of Nova Scotian Granites and Slates (Reynolds, Muecke and Zentilli) - A continuing detailed investigation, the initial results from which will be published early in 1977.

5. McGill University - Department of Geological Sciences

Investigator: R. Doig.

Northwest Grenville Province - The regional Rb-Sr geochronological study in La Vérendrye Park has been completed. Reworked Archean Rocks have been identified in a probably continuous segment extending from the Grenville Front near Val d'Or to about 125 km southeast of the Front. The southeastern boundary of this Archean segment is marked by a broad zone of migmatites, many of which yield ages of about 1150 m.y., but high $^{87}Sr/^{86}Sr$ initial ratios. This zone also includes a lithologically distinct metasedimentary unit which yields an age of granulite facies metamorphism of 1650 m.y. and little indication of an earlier crustal history. In summary there is evidence for three distinct episodes of high grade metamorphism in this northern segment of the Grenville province.

Anorthosite suite rocks - Additional investigation of the Morin anorthosite complex has shown that both the mangerites and anorthosites crystallized with a range of $^{87}Sr/^{86}Sr$ ratios, and some of the mangerites post-date crystallization of the anorthosite by about 100 m.y. We have recently obtained a date of 1418 m.y. for the Nain anorthosite, based on pegmatitic segregations within the anorthosite. Unfortunately, these datable segregations are exceedingly rare, and very difficult to recognize in the deformed anorthosites of the Grenville province.

Bear-Slave Structural Province boundary N.W.T. - Begun in 1972, and completed in 1975, this work has made it possible to identify a basement to the Archean Yellowknife Supergroup, and to describe in detail the geographic and temporal distribution of metamorphism and/or plutonism over the time span of 1900 to 3000 m.y. ago. A majority of the granitic rocks within the Bear Province near its eastern margin have been derived at least in part from Archean rocks.

The granulite terrain west of the Labrador trough consists of a fairly continuous suite of hornblende and pyroxene subfacies granulites. Ages of five units from this area yield ages of 2500 to 2900 m.y. which are not all statistically distinct. Initial ratios are very low. However, because of very low rubidium contents, and other petrographic and textural evidence, a supracrustal origin cannot be precluded.

Eclogite nodules from kimberlite pipes of the Colorado Plateau have been shown to be samples of Fransiscan-type oceanic crust. This work may represent the first well-documented sampling of oceanic crust which has been subducted (a distance of 1200 km) beneath a continental plate.

Current projects continuing into 1977 include isotopic studies of the Seven Islands anorthosite suite, granitic rocks associated with uranium mineralization, and the section of the Grenville Province between Seven Islands and Havre St. Pierre.

6. McMaster University - Department of Chemistry

Investigators: C.E. McEwing, J. Monster, C.E. Rees and H.G. Thode.

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

Measurements of the four stable sulphur isotopes (^{32}S, ^{33}S, ^{34}S, ^{36}S) are being made on lunar and meteorite samples to investigate the history of the lunar regolith and the isotopic homogeneity of the early solar system.

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

Department of Geology

Investigators: D. Birk, J.H. Crocket, A. Fallick, D.C. Ford, M. Gascoyne, R.S. Harmon, F. Longstaffe, R.H. McNutt, D. Paul, H.P. Schwarcz and J.M. Wolff.

Stable Isotope Geochemistry - Oxygen isotopic and geochemical studies of Archaean rocks: Low to medium grade metagreywackes are distinctly lighter than Phanerozoic equivalents, reflecting high contents of largely unaltered volcanic detritus. With increasing grade of metamorphism and migmatization, a shift to lower $\delta^{18}O$ values occurs. Weakly metamorphosed volcanics are heavier than fresh equivalents. Granulite facies para- and orthogneisses are isotopically indistinguishable, with $\delta^{18}O$ ranging from 7 to 9%. (Schwarcz, McNutt and Longstaffe)

Stable isotopic studies of speleothem: Paleoclimatic studies of speleothem are continuing, using oxygen isotopic variation in successive, radiometrically dated layers of individual stalagmites, etc., to infer changes in cave temperature. Fluid inclusions of these speleothems are now being analyzed for both $\delta^{18}O$ and δD values to test whether waters trapped in them are representative of ancient meteoric water. Samples from Vancouver Island, B.C., Bermuda, Jamaica and Yorkshire, England are being studied, in order to compile a global record of climatic variation during the past 200,000 years. (Schwarcz, Ford, Fallick and Gascoyne)

Uranium Series Disequilibrium Dating - Paleo-sea level variations: Stalagmites from a flooded portion of a cave in Bermuda have been dated by

$^{230}Th/^{234}U$ methods to establish the time when growth ceased due to drowning by rising sea water. The resultant curve of sea levels gives information on low sea-stands during the last and penultimate glacial epochs which is complementary to highstand data obtained from raised coral reefs. (Schwarcz, Harmon and Ford)

Dating of Paleolithic archaeological Sites: Many Paleolithic sites contain layers of travertine, either in caves or on spring-deposited tufa terraces. It is possible to date these by $^{230}Th/^{234}U$ ratio measurement. Samples from Greece, E. Germany and Israel yield dates for lower Paleolithic sites of 220,000 to 140,000 years and Middle Paleolithic sites from 130,000 to 60,000 years B.P. Dating of mollusean aragonite may yield ages on raised beaches in Canadian Arctic. (Schwarcz and Fallick)

Sr and Pb Isotopic Studies - Andean Orogenic Zone: Bolivian Sn and W bearing plutonic rocks of two distinct age groups, ca. 200 and 20 m.y. are being analyzed for their Sr and Pb isotopic compositions. Major element and REE abundances have also been done. We are trying to see if the source region for the magmas (and hence and Sn and W?) has significantly changed for the two groups of rocks. This is part of a larger study being done in the Andes of Bolivia, Chile and Peru. (Paul, McNutt and Crocket, with A. Clark, Queen's University)

Archean Greenstone Belts - Rb/Sr whole rock ages are now complete on five "younger" K_2O-enriched stocks that intrude the volcanic components of the belts. They range in ange from 2.58 to 2.64 Ga, with initial ratios varying from .7001 to .7015. The field area is between Fort Francis and Dryden in the Wabigoon belt of N.W. Ontario. (Birk and McNutt)

A geochemical investigation of the supra-crustal volcanic and plutonic rocks at Kakagi Lake, N.W. Ontario, reveals the possibility of a cogenetic suite. Rb/Sr whole rock isochron work is underway to determine the contemporaneity of the two suites. (Wolff and Crocket)

Department of Physics

Investigators: W.B. Clarke, Z. Top, R. Vicencio and M. Bahrani.

Rare Gas Isotopic Studies - Extensive measurements of inert gases and tritium in terrestrial waters (oceans, lakes, ground water) are being continued. Projects presently in progress include:

- Development of ^{3}He as an oceanographic tracer;
- Measurements of ^{3}He and tritium in the oceans above the thermocline and in certain lakes to determine mixing time scales;
- Measurements of ^{3}He, ^{4}He, Ne and tritium in groundwater and lakes near uranium deposits with a view to developing a prospecting method based on excess dissolved ^{4}He; and
- Determination of the helium isotope solubility effect in water, heavy water and sea water at closely spaced temperature intervals.

7. Queen's University - Department of Geology

Investigators: E. Farrar, S.L. McBride, D.A. Archibald, R.J. Knight and R. Tosdal.

Several geochronological investigations are currently underway - A study of the chronology of intrusion and mineralization in the Bolivian and northern Chilean Andes has become focussed on mineral age discordances observed in some batholiths. The $^{40}Ar/^{39}Ar$ technique is being employed to try to resolve these discordances. (S.L. McBride and E. Farrar)

- A K-Ar geochronological study of the south-eastern part of the Kootenay arc British Columbia, between 49°N and 50°N, is in progress. The research is concentrated on the Payonne Batholith and surrounding metamorphic and plutonic rocks. The aim of this research is to determine the age relations of the intrusions comprising the batholith and thereby to determine the role of the batholith in the structural and metamorphic history of the area. (D.A. Archibald and E. Farrar)

- A continuing investigation into the problems of initial argon in amphiboles of the Tulameen complex in southern B.C. through the use of the $^{40}Ar/^{39}Ar$ incremental heating technique. (R.J. Knight and E. Farrar)

- An investigation aimed at determining the temporal relationships between vulcanism, deformation and mineralization in the Andes of southern Peru is underway. (R. Tosdal and E. Farrar)

8. University of Toronto - Department of Physics

Investigators: G. Berger, R. Bottomley, R.M. Farquhar, I. Fletcher, C.M. Hall, J. Hanes, Y.F. Huang and D. York.

Lead Isotope Studies (Fletcher and Farquhar) - The study of lead isotope ratios in sulphides from Grenville and associated rocks, has been continuing. A number of additional occurrences have been sampled in southern Ontario, and specimens have been obtained from Newfoundland, with a view to defining the nature and extent of the isotopic variations already observed. On a $^{207}Pb/^{204}Pb$ against $^{206}Pb/^{204}Pb$ plot, the data appear to define a linear sequence; the slope of the line is consistent with additions of radiogenic lead generated between about 1.3×10^9 to 0.9×10^9 years ago, although some of the leads that fit the line occur as replacements in Paleozoic cover rocks. The least radiogenic leads have isotopic ratios which lie below the current terrestrial lead isotope growth curve; isochron ages for these leads are about 1.3×10^9 years, corresponding roughly to the time of deposition of the major (now metamorphosed) sediments of the Grenville.

Comparison of our data with earlier isotopic analyses by others, of lead from Balmat, N.Y., suggests that our least radiogenic leads and Balmat lead may represent a contemporaneous suite of samples having respectively marine-volcanic and continental associations. The Balmat leads have higher $^{207}Pb/^{204}Pb$ ratios, and have evidently developed in an environment which on the average has been richer in U than that in which our Grenville samples have evolved. Lead from deposits close to Balmat appear to be a mixture of the main Balmat lead and the least radiogenic Grenville leads.

The Grenville isochron appears to contain a geographically and geologically extensive set of sulphides. The inclusion of samples of post-Cambrian age is surprising, and the mechanism whereby these samples could be emplaced and retain their affinity with the isochron is not known. Mississippi valley leads define a different isochron, but it is possible that the least radiogenic of these may lie on the Grenville isochron.

In addition to broadening the sample base, Mr. Fletcher has greatly improved the reproducibility of analyses, through improved sample loading methods, installation of a new ion current detector, and a field controlled peak hopping mass scan system.

Fission Track Studies (Huang and Farquhar) - The spark counting apparatus developed in this laboratory has been modified and partly automated by Dr. R.H. McCorkell of Bondar-Clegg Co., Ottawa, for the purpose of measuring uranium contents of natural water samples. The apparatus has a potential sensitivity of .001 ppb.

Optical viewing of track densities in plastic foil track recorders used to map uranium distributions in the sections of the quartzes measured previously indicate that the uranium in the samples is distributed uniformly. Efforts are being made to etch tracks in the quartzes after bombardment by fission products from ^{252}Cf.

^{40}Ar - ^{39}Ar Dating of Impact Structures (Bottomley and York) - The establishment of the ages of the various terrestrial meteorite craters will enable an accurate estimate to be made of the variation in time of the meteorite flux at the earth's surface. This is an important function in discussions of the evolution of the solar system. Crater ages also help in calculations of erosional rates of shield areas. Impacts are best dated by $^{40}Ar/^{39}Ar$ studies and we have for some time been applying this technique to crater samples in collaboration with R.A.F. Grieve, P.B. Robertson and M.R. Dence of the Earth Physics Branch of the Department of Energy, Mines and Resources.

A series of impact generated melt rocks and some shocked country rocks from a number of Canadian and Scandinavian craters are being studied by the ^{40}Ar - ^{39}Ar dating method.

Reconnaissance dates have been completed on four Scandinavian locations: Dellen (≃230 m.y.), Mien (≃120 m.y.), Siljan (≃360 m.y.) and Saaksjarvi (≃490 m.y?). In addition, a series of age determinations has been made on samples from Lac Couture, Lac La Moinerie and the Slate Islands in Canada.

The age plateaux from three different melt rocks from Lac Couture seem to indicate an age of impact of about 420 m..y. B.P. All three samples show a good plateaux over 80% of the released gas. Likewise, three whole rocks from Lac La Moinerie show good plateaux and indicate an impact age of 400 m.y. or less. Since the rocks from these two Canadian craters and the Scandinavian sites are melt rocks, they were probably subjected to pressures in excess of 400 kbar. This type of rock seems to give reasonably good plateaux in most cases. This was also noted earlier in the project in a study of melt rocks from Lake Mistastin. However, we have found that basalts and diabases that are not so highly shocked do not appear to be reset. This is shown by a series of dates on rocks from six locations from the Slate Islands. These yielded pre-impact Keweenawan ages in the range 900-1100 m.y.

Good plateaux were not always obtained on Keweenawan rocks from other portions of the Shield. The rocks in question were not shocked above 100 kbar. Only one rock showed an age which might be related to the impact event. Three analyses of this rock gave ages that ranged from 320 to 500 m.y. These ages apparently represent argon loss, but preliminary indications are that this loss is a result of alteration of the potassium-bearing minerals rather than a resetting due to heat or shock associated with the impact.

Ar^{40}/Ar^{39} Dating of Grenvillian Paleopoles (Berger, York, with Buchan and Dunlop, University of Toronto) - The directions of natural remanent magnetizations (NRM) from Grenville rocks define paleopoles lying in two adjacent groups, one of which is distinct from paleopoles found for other structural provinces of the Canadian Precambrian Shield. The proposed explanations for the Grenville paleopoles are of three types: (a) These poles define a "Grenville Loop" in the polar wander curve that predates the (Proterozoic) Logan Loop. (b) The "Grenville Loop" postdates the Logan Loop. Both of these hypotheses simply rapid drift of the entire Shield. (c) The third invokes collision of a Grenville plate with the Superior. In this case, the Grenville poles near the younger end of the Logan Loop manifest the convergence while those furthest away would be older. A choice among (a), (b) or (c) depends critically upon the relative ages of the magnetizations.

One suite of rocks yielding two directions of NRM from the same specimen is in the Haliburton area. In particular, samples from the Glamorgan gabbroic

complex and the Dudman and Bark Lake diorites give "A" and "B" paleopoles about 60° apart. The A direction lies farthest from the Logan Loop and is thought to have been acquired as a TRM before the B. It has been argued that A directions manifest cooling through temperatures above 500°C while B directions were acquired below 500°C, but above 100°C. Conventional K-Ar dates from biotites in this area cluster near 900-950 m.y., while U-Pb and Rb-Sr dates are from 100 to 300 m.y. higher. Because of its potential in revealing partially reset dates, the Ar^{40}/Ar^{39} method is particularly apt for polymetamorphic terrain.

For the Ar^{40}/Ar^{39} dating, rocks from 3 sites within the Bark Lake intrusive were selected initially and 7 mineral separates were irradiated with fast neutrons.

The interpretation of the very detailed age spectra obtained depends on our knowledge of the characteristic Ar^{40}/Ar^{39} signatures of hornblende and biotite. The spectrum for the one biotite sample for which data have been completely processed is extremely well behaved between 600° and 1200°C. Previous work has shown clearly that such a result precludes a partial thermal overprinting, but is instead consistent with slow cooling from high temperatures. Because coarse biotite closes to Ar loss below about 200°C under geological conditions and because this spectrum is flat, no secondary thermal event greater than 200°C and later than ≃920 m.y. affected this sample. Correspondingly, the spectrum for a hornblende indicates that it probably closed to Ar loss, which occurs only above about 500°C, approximately 70 m.y. before the biotite date.

In summary, these results are similar to previous conventional K-Ar dates from the Haliburton area and are consistent with hypothesis (b) above. In this case, however, the earlier half of the Grenville Loop remains to be recognized in North American rocks. Further Ar^{40}/Ar^{39} analyses are in progress. In addition, we are attempting to refine and test a theoretical model that relates the integrated Ar^{40}/Ar^{39} apparent age to the temperatures at which Ar loss ceases in a high-grade metamorphic terrain.

^{40}Ar-^{39}Ar Dating of Young Basalts (Hall and York) - Theoretically, the K-Ar dating technique can be used for volcanic rocks which are as young as 10,000 or 20,000 years. Practical considerations, such as chemical alteration yielding high atmospheric Ar contamination levels, often degrade precision severely for rocks of such young ages. However, in 1975, it was demonstrated that three fresh samples of basalt from the Laschamp - Olby lava flows in central France, (correlated with the Laschamp geomagnetic reversal) yielded consistent and reproducible apparent ages averaging about 45,000 y.

In order to rule out the possibility of excess ^{40}Ar being inherited in the samples, analyses of mineral separates are necessary. However, the fine grained texture of the samples makes such a separation difficult. Initial studies were done on a basalt from the Asama volcano in Japan which is approximately (from ^{14}C dating) 20,000 y. old. This sample displays large phenocrysts which are easily separable. The results confirm that phenocrysts can have large components of inherited Ar. A pyroxene mineral separate yielded an age of $24.0+/-3.7 \times 10^6$ y., which is about two orders of magnitude too high. This behaviour in the phenocrysts explains the fact that whole rock analyses of this sample give wildly varying amounts of excess ^{40}Ar.

All attempts to date a finely crushed sample of basaltic ground mass have failed, because the sample picks up a large, tenaciously held, atmospheric Ar contamination when crushed smaller than about 150 mesh. Typically, a chunk sample gives an atmospheric level of about 7×10^{-8} ccNTP/g while a crushed sample may give 2×10^{-6} ccNTP/g. Last year, several attempts were made to crush samples which were frozen with liquid N_2. This failed to produce lower contamination as did crushing under liquids. A ball mill which can be

evacuated has been designed, and crushing in a vacuum will be attempted this year.

Two multi-step heating experiments were performed on Laschamp-Olby samples. In both cases, most or all the radiogenic argon was released in a few heating steps. For a Lashamp chunk, one analysis (CMH-43) gave an apparent age at 790°C of 49,000+/-26,000 y. which accounts for all expected radiogenic ^{40}Ar. Similarly, for an Olby coarse powder, the two fractions above 1110°C give a total age of 47,200+5800 y. These encouraging step-heating results plus a re-examination of $^{40}Ar/^{39}Ar$ errors will lead to $^{40}Ar/^{39}Ar$ dating of extremely young basalts this year.

^{40}Ar-^{39}Ar Study of Thermal Metamorphic Events (Hanes and York) - During the past year, we have continued the ^{40}Ar-^{39}Ar geochronological study on Precambrian rocks as outlined in last years report.

In review, Munro township, Ontario, lies within the Abitibi greenstone belt of the Superior Province. Since the Kenoran reworking of the Archean basement, two major Precambrian thermal events, marked by diabase dike emplacement, have occurred in the area: the Matachewan and Abitibi events of age 2690 m.y. and 2147 m.y. respectively (Rb/Sr ages; Gates, 1970). We have carried out detailed whole-rock and mineral separate ^{40}Ar-^{39}Ar dating on two of these intersecting dikes in Munro township - a 25 metre wide N/S trending Matachewan dike, and a 75 metre wide NE/SW trending Abitibi dike. Previous paleomagnetic work (Irving and Naldrett, 1976; in press) on these same dikes indicated that the Matachewan dike has been reset by the Abitibi intrusion to a distance of 80 metres from the contact, beyond which Matachewan directions are retained. The present study provides a unique opportunity to compare the Ar age behaviour with the magnetic signature.

In the past year, we have obtained considerable data which further support the evidence, mentioned last year, of a third thermal event, undetectable geologically in the area, of 'Hudsonian' age (1700-1800 m.y.).

Whole rock and feldspar mineral separates from the Matachewan dike provide evidence of both the 2.1 b.y. thermal overprint of the Abitibi dike emplacement, and the 1.7-1.8 b.y. resetting event. Mafic separates, on the other hand, yield a minimum estimate (2.4-2.5 b.y.) for the Matachewan intrusion. As yet, no samples have yielded a good plateau age coincident with the 2690 m.y. Rb/Sr age. The Matachewan samples indicate a more complex geochronologic relationship than suggested by the simple magnetic behaviour, with no readily apparent relationship between the observed age data and the distance of the samples from the contact.

Feldspar and mafic separates from the center of the Abitibi dike yield excellent plateau spectra coincident with the 2147 m.y. Rb/Sr age. However, spectra from mineral separates taken near the edge of the dike demonstrate plateaus with a 1.7-1.8 b.y. age. Apparently grain size may be an important parameter of the susceptibility of the Abitibi samples to thermal overprinting. Thus far, Abitibi samples have yielded either a 2.1 b.y. or 1.7-1.8 b.y. plateau; no intermediate dates were obtained.

A preliminary analysis of a pyroxenite country rock sample yields a saddle shaped spectrum whose higher temperature fractions are dominated by excess argon. The median temperature fractions, however, suggest an age of 2.8 b.y., which may be construed as either a maximum estimate for its time of intrusion, or a maximum estimate of the time of overprinting by the 2.69 b.y. Matchewan event. A feldspar separate from this sample gives a 2.1 b.y. age, and has thus been reset by the Abitibi event.

9. University of Western Ontario - Department of Geophysics

Investigators: A. Hayatsu, B. Merz and H.C. Palmer.

K-Ar ages of Sudbury Diabase Dikes (Merz, Hayatsu and Palmer) - The dating survey of the dikes cutting across the Grenville Front revealed unexpectedly scattered K-Ar ages within the Southern Province including anomalously old ages close to the Grenville Front. The old ages were attributed to the presence of initial argon with very high initial $^{40}Ar/^{36}Ar$ ratios, because apparent ages of minerals within each rock sample vary systematically with $^{40}K/^{36}Ar$ ratio.

Ages in the range 400 to 435 m.y. were also found in the Front region. The young samples are significantly different in composition from the rest, suggesting that these samples come from a lower paleozoic dike or dikes and that the use of apparently one dike swarm as a stratigraphic time marker requires caution.

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VI METEOROLOGY AND ATMOSPHERIC SCIENCE

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1. Introduction

The level of activity in Canadian meteorological and atmospheric science continued at nearly the same level as in the past few years. The financial restrictions have had the effect of reducing some activities but major programs, such as the Stratospheric Balloon Project and the development of the FGGE buoys have continued. One result of the former was the AES Advisory Committee Report calling for a reduction by one half of the current rate of emission of fluorocarbons.

The Scientific Committee and its sub-committee, the GARP Scientific Committee of Canada, have continued to be active during the past year. Their recommendations on scientific activity have had a significant effect on the types and emphasis of scientific research over the years.

The Canadian Meteorological Society held its Tenth Annual Congress at Université Laval from May 26-28. The theme of the Congress was "Les réseaux d'observation". As with the Ninth Congress there were sessions on both oceanography and meteorology. The Society's awards for 1975 were awarded to: Gordon A. McKay, Prize in Applied Meteorology; Dr. Helen Warn, Graduate Student Prize; Waldimar L. Gutzman, Rube Hornstein Prize in Operational Meteorology. A citation was awarded to Tony Le Sauteur for his efforts to increase public awareness of environmental issues and to bring the awareness into focus through contractive action. The CMS continues to be in good financial shape and its journal Atmosphere has gained further stature and recognition. The CMS executive is now centered in Vancouver, the first time that it has been outside the Toronto-Montreal area.

2. The University of British Columbia - Department of Geography

(a) Energy budget of an urban canyon

An urban canyon (a street and its flanking buildings) was selected and intensively instrumented to measure the radiative, conductive and turbulent heat flows both within the system, and between the canyon and the atmosphere above. In this manner it was possible to monitor the complete energy balance of a typical unit of the urban 'surface'. An

especially innovative portion of the project involved the study of the energy balance of the air volume contained within the canyon. This permitted direct study of the atmospheric physics governing air temperature changes in an urban area. Short-wave radiation measurements showed the albedo of the canyon system to be a complicated function of time and that the effect of geometry is to increase net solar radiation absorption. Long-wave radiation results revealed the effects of the reduced canyon sky-view factor in trapping radiation. Long-wave radiative flux divergence in the air was shown to be the dominant process in air temperature change when winds were light. The canyon divergence results contrasted sharply with those from above roof-level, and in rural areas. The change is consistent with the view that this is a primary cause of the urban heat island effect. If this is corroborated elsewhere it represents a significant breakthrough in our understanding of urban climate modification, and provides a physical basis for urban climate modelling. The surface energy balance data showed partitioning between the sensible and latent heat fluxes, and heat storage, which is consistent with the areal estimates gained through project (b) below. Preliminary estimates of the magnitude of horizontal heat advection were also obtained.

(b) Areal urban sensible heat flux

Sensible heat fluxes have been measured over Vancouver, B.C. and Uppsala, Sweden. In both cases the data were obtained using an eddy correlation instrument developed in previous projects. The system was mounted at a height of 50 m on masts in both cities, and in Uppsala was supplemented by 8-level profiles of air temperature, humidity and wind speed up to a height of 100 m. The field phase is complete and data analysis is continuing. The aim is to identify the nature of the heat flux from cities in North America and Europe, to compare and contrast their general features, and to parameterize the flux in terms of basic surface characteristics suitable for numerical modelling. Several special urban characteristics are emerging including the fact that nocturnal heat flow is in the opposite direction to that in rural areas, and that day-to-day variability seems to be related to mesoscale meteorological conditions, especially the humidity regime. The partitioning of energy between sensible and latent heat is proving to be surprising in that evaporation is stronger than had been previously speculated.

(c) Building and settlement energy balances at Inuvik, N.W.T.

The study was based on measurements made in Inuvik during the period of polar night (Dec. - Jan.). The project investigated both the effect of the external climate upon the building and settlement anthropogenic heat use, and the reverse effect of the anthropogenic heat release upon the town's climate, viz:

(i) The effect of the external climate upon the energy demand was investigated by a statistical analysis of records of heat production by the central heating plant and the standard Inuvik airport meteorological records (air temperature and wind speed). Regression analysis yielded good correlations ($r^2 > 0.90$) for both hourly and daily periods. The effect of a time lag between weather change and demand was also investigated.

(ii) Heat loss through the cladding of the Inuvik Research Laboratory was studied from direct measurements of radiation and temperature gradients, and a knowledge of the thermal properties of the construction materials and design. Special emphasis was placed on heat flow through double-glazed windows. Heat transfer coefficients were established for turbulent losses and showed good agreement with laboratory and field studies on other objects.

(iii) The influence of settlement heat releases upon the net long-wave radiation balance was examined based on simultaneous town and tundra measurements. The town balance was consistently more negative. This was attributed to the excess warmth of the town, and was linked to the anthropogenic energy releases. An analysis of the relation between measured clear sky counter radiation and that calculated from four empirical formula revealed that the Idso and Jackson (1969) equation is most suitable for arctic applications. Unsatisfactory results were obtained with the corresponding net long-wave equations.

(iv) The impact of arctic 'urbanization' upon the surface energy balance and climate was investigated from measurements and a numerical boundary layer simulation model. Comparisons between the measured and computed energy balances and heat islands were reasonable. With cloudless skies in January typical values were:

Location	Net radiation ($W\ m^{-2}$)	Sensible heat flux ($W\ m^{-2}$)	Anthropogenic heat flux ($W\ m^{-2}$)	Heat island (°C)
Inuvik	-39	- 7	46	1.5
Tundra	-32	32	0	

(d) Calculation of Shortwave Radiation at the Earth's Surface

Due to the spatial variability in shortwave radiation the standard AES radiation network cannot present the shortwave radiation field with the required spatial resolution. Semi-theoretical models, which use more widely available hourly meteorological data have been developed and shown to be capable of estimating, with acceptable accuracy, the direct, diffuse and total shortwave radiation on a daily basis for both clear sky and actual cloud conditions. The model is currently being used to describe the synoptic-scale variability of shortwave radiation over British Columbia. Another model, used to separate the total shortwave radiation into its direct and diffuse components, has been developed and shown to have widespread applicability.

(e) Measurement of Shortwave Radiation on Inclined Surfaces

The current interest in developing solar radiation as an alternate energy source has highlighted the inadequacy of the radiation observing network. In particular there is an acute absence of observational data for inclined surfaces which is required both for feasibility studies and in the development and testing of methods for transforming horizontal surface data (measured or modelled) to inclined surfaces. Half hourly totals of shortwave radiation on horizontal (total, direct, diffuse) and 30, 60 and 90 degree south-facing surfaces are currently being measured in Vancouver. The data (together with a similar set from Toronto) will provide a good base for subsequent studies of the shortwave radiation regime of inclined surfaces.

(f) The Availability of Solar Energy in Canada

Numerous studies of the climatological constraints on the development of solar energy in Canada have been completed and further studies are in progress.

(g) Aspects of the Synoptic Climatology of British Columbia

Ten years of daily synoptic weather data have been analysed in order to characterize the nature, frequency and persistency of synoptic weather types, fronts and pressure systems over British Columbia and the adjacent area of the north Pacific Ocean. The results have been used to describe the synoptic climatology of the area and as a basis for studying the spatial and temporal variability of the precipitable water and shortwave radiation fields.

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

(a) Precipitation Physics

The year 1976 saw the following accomplishments in cloud physics by Dr. E. P. Lozowski and his associates. M. Oleskiw completed a dissertation on cloud chamber simulation of graupel growth, and is currently examining the feasibility of field measurement of the details of hailstone tumbling. R. D'Amours has produced a hailstone growth model in which non-equilibrium heat transfer and internal conduction play a significant role. L. Wojtiw has measured hail impact energies with sparse and dense hailpad networks, and has performed Monte Carlo experiments to examine the accuracy of energy measurement as a function of network density. E. Lozowski has simulated the results of a randomized hailstorm seeding experiment in order to determine the experimental duration required to detect seeding effects of a particular magnitude. T. Krauss is examining the variation of radar parameters with time in seeded and unseeded hailstorms.

Dr. R. Charlton and his associates worked on the following cloud physics studies during 1976. P. Wrenshall, an M.Sc. student, has shown a strong correlation between radar echoes and hailfall measurements at the ground. This study will be used in the evaluation of the Alberta Hail Project's hail suppression program. Studies of O^{18} and D in precipitation and water vapour samples are proceeding toward the goal of determining the usefulness of such information in understanding precipitation processes. Numerical models of the growth by accretion of ice crystals were discussed at the annual CMS congress and further studies by R. Charlton and L. Cheng, currently of the University of Toronto, are proceeding. A study of industrial fog in the Alberta Oil Sands development area was completed for the Alberta Oil Sands Environmental Research Program with Stanley Associates Engineers as the contractor. Studies of cooling tower plumes in Edmonton at very low temperatures are just beginning. These cooling towers contribute about one-half of Edmonton's water vapour emissions during days of ice fog potential.

(b) Biometeorology

An intensive microclimatological observation program within and above mature Jackpine (Pinus Banksiana) on a steep sand slope in northern Alberta was undertaken in support of an interdisciplinary study of the long-term stability of vegetation on tailings ponds dikes for the Alberta Oil Sands Environmental Program.

Measurements of nutrient concentrations in precipitation and dry deposition fluxes of nutrients in the Cooking Lake moraine area of central Alberta were completed. Large dry-to-wet deposition ratios were found for almost all compounds and ions that were measured.

(c) Hydrometeorology

Monthly and seasonal lake evaporation estimates for Lake Wabamun, Alberta derived from a stability-dependent mass transfer equation applied to hourly data from the summer of 1973 showed no significant departure

from estimates derived using a constant mass-transfer coefficient. Comparisons between mass transfers estimates and covariance measurements are underway for selected short periods.

Oxygen isotope ratios in precipitation in Alberta suggest that local water vapour sources are dominant in summer. This hypothesis is being used in a study of dry spells with a view to possible application to the prediction of low relative humidities for fire index and other uses.

(d) Micrometeorology

A one-dimensional second-order closure model from the hierarchy proposed by Mellor and Yamada was programmed and applied to the urban heat island problem. Although the model produced reasonable sequences of mean and turbulent variables through a 24 hour period it appears that moisture must be included in order to simulate major climatological features of the heat island.

(e) Synoptic-scale Studies

R. Hopkinson is employing NOAA-4 imagery to investigate the distribution of cloud associated with objectively-defined synoptic weather types occurring in Alberta and British Columbia. D. Oracheski is completing a similar study of weather systems crossing the Western Cordillera. He is using visible and infra-red imagery to assess the effect of the mountains on cloud bands generated by Pacific storms.

P. Scholefield used 27 years of data to examine the relationship between objectively determined surface isobar configurations and associated weather. He calculated the percent probabilities of aviation weather parameters associated with various map types, and used them in conjunction with ceiling and visibility categories in a conditional-probability model. In this manner, Scholefield obtained a useful catalogue of surface-map types indigenous to the Mackenzie River Basin in winter. The catalogue comprises a summary of the occurrence and pressure patterns of map types, and a chronological listing of the types assigned to each of some 3800 maps in the data base. Several interesting relationships between map types and climatic anomalies have come to light.

4. Alberta Research Council - Atmospheric Sciences Division

The research program of the Atmospheric Sciences Division (ASD) of Alberta Research contributed this year to the on-going Alberta Hail Project (AHP) and to the Alberta Oil Sands Experimental Research Program (AOSERP).

The Storm Environment Program completed the analysis of two sequential sounding days from the 1975 Alberta Hail Project season, August 21 and 27. On August 21, severe convection with large hail occurred in the northeast part of the project area. On August 27, activity was spotty with only a handful of hail reports coming, again, from the northeast. Analyzed were sounding data, numerical cloud model output data, synoptic charts, teletype messages, and radar and precipitation data. The analysis showed that on August 21, in the northeast part of the project area, the airstream was convectively unstable, low-level moisture content was high, and upper-level winds were strong. Mid-level cold-air advection followed by diffluence and upward vertical motion occurred, which explains the intensification of convection. Further south, low-level moisture content was not as great and mid-level diffluence was not significant, so convection resulted primarily in rainfall.

On August 27, the absence of adequate low level moisture in all but the northeastern part of the AHP area was confirmed, although middle level instability was observed in the Calgary area. This lack of moisture precluded severe convection there. The slight destabilization associated with the

encroachment of a weak thermal trough into the region of highest surface dewpoints probably accounted for the isolated activity on August 27. Research is in progress to objectively determine optimal positioning and timing of atmospheric soundings to insure that they sample air participating in hailstorm circulations and atmospheric conditions immediately prior to first radar echoes of the day.

The numerical simulation program has been concerned with the use of simple numerical cloud models as a potential tool for evaluating seeding techniques. A preliminary evaluation of model predictions suggested that the usefulness of the models as a forecasting tool is rather limited, because of difficulties experienced in forecasting afternoon moisture conditions. However, when a temperature and humidity sounding close in time and space to the storm and the measured cloud base height and temperature are used as input, the models give useful predictions. For instance, during the summer of 1975, measured cloud base parameters were available for 14 days. In addition, mobile rawinsonde soundings, taken at most a few hours prior to and physically close to the storm, were also available for most of the 14 days. For these days, predicted maximum hailstone diameters were found to closely correspond to reported maximum hailstone diameters, the correlation coefficient being better than 0.85 and statistically significant at the 0.5 percent level.

Predicted maximum hailstone diameter is derived from model calculations of the maximum vertical velocity and the cloud temperature at that maximum, and from an empirical nomogram. It is recognized that other calculated parameters might also correlate highly with measurements, so many parameters from the models were correlated with reported maximum hailstone diameters. For most calculated parameters related to storm energy, water content and equivalent potential temperature, the correlation coefficient is 0.9 or better. Other measured parameters aside from maximum hailstone size are being investigated.

This summer (1976) a concerted effort was made to measure cloud base parameters for storms on days when no seeding occurred. It is hoped that the high correlations between measurements and calculated parameters obtained for days on which seeding occurred can be obtained for no-seed days, and that the various relationships observed can be tested for differences between seed and no-seed days.

In the Radar Studies Program, a detailed account of the kinematic structure of hailstorms has resulted from interpretations of fine-scale radar reflectivity patterns. This general study, supported by independent studies from other parts of the globe, demonstrates the variable nature of hailstorms. The results are of particular relevance since up to this time some storms were considered to be reasonably steady. Interpretations of data from this study have provided the basis for improving cloud seeding methods in Alberta, where the intent is to promote beneficial competition among hail embryos and thereby reduce hail. Attempts are now made to seed storms, as often as new fine-scale patterns form, because some fine-scale patterns are apparently a manifestation of hail production.

In connection with the macrophysical radar reflectivity pattern studies, a program is being conducted to outline the physical properties of the 'new growth region'. Extension with time of the fine scale patterns to their origin suggests a juxtaposition on the edges of hailstorms of newly-formed fine-scale patterns and new cloud growth. The competition concept of hail suppression requires that reagent be injected into potential hail generation regions well before hail formation. Consequently, characteristics of the new growth zone are being studied because this zone is thought to contain the 'shelf' cloud, a structure which probably represents the earliest stage of precipitation (perhaps hail) growth. The new growth zone is being studied with respect to its frequency of occurrence, height above ground, and thickness, and to the time dependence of small cloud elements which it contains. Early results obtained from photographs taken from aircraft are

consistent with previous stereophotogrammetric work conducted in Alberta. These results support the previously held - but often contested - concept that hail production is concurrent with time dependent updrafts.

In contrast to the macrophysical radar reflectivity pattern analyses and cloud photography, microphysical studies of hydrometeors are conducted using the multichannel recording capability of the Alberta Research Council's polarization diversity radar. Based upon previous hail detection efforts, these continuing radar studies attempt to determine distributions in space and time of various hydrometeor types. Such space-time distributions are of prime concern for hail suppression methodology. Early studies made use of the two intensity components of the signals received by the radar; however, engineering progress during the past year now provides the capability of also recording two phase components. The two phase components, together with the intensity components, may permit distinction among hydrometeors based upon their orientation state; earlier attempts were based mainly upon interrelated parameters such as the number, density, size, and shape of hydrometeors. The new capability is expected to greatly aid differentiating among hydrometers, since earlier work conducted in Alberta suggests that hail falls with a much more random orientation than rain.

Along with radar studies of hydrometeors, a raindrop distrometer is being used to measure distributions with size of rain at the surface. Detailed comparisons of distrometer measurements of rainfall and radar measurements of rain are expected to help solve the general problem of distinguishing rain from other types of precipitation within hailstorms. In fact, the distrometer observations are carried out as part of a larger program which aims to record both rainfall and hailfall events at the surface, and to relate these events to multichannel radar observations.

The Hailfall Study Program to relate hailstone parameters to hail damage to crops of varying type and maturity was continued this year. The dense hailpad network of 162 stations in 922 square kilometers in the Rimbey area was again operated during the summer to gather quantitative data. Besides hailpads, eight wind stations and three hygrothermographs were operated in the network to obtain information on wind, temperature, and relative humidity during the storm. Considerable data on the precipitation variables and crop damage were obtained from volunteer observers within the network. Additional crop damage estimates were obtained for the storm of August 15 by an adjustor from the Alberta Hail and Crop Insurance Board. To study the problem of fine-scale discontinuities of hailfalls on the surface, two micro-dense networks of 26 and 16 hailpads in 0.64 square kilometer were located in the dense network and serviced during the summer. In each of the micro-dense networks, a hailcube was set up to give estimates of the horizontal component of the impact energy. A study of the six storms which crossed either or both of the micro-dense networks should yield a more accurate description of discontinuities of hailfall for Alberta storms. The two mobile sampling units were again used this year to intercept hailstorms and collect hail and rain samples, to expose hailpads, and to collect wind information during the storms.

The study of the dispersion of the silver iodide (AgI) used in the cloud seeding program was continued. In 1975, 2236 samples were analyzed. Of these, 494 were collected prior to any seeding operation for the year and were used to determine background silver concentration in convective precipitation. The background study showed that more than 97 percent of the samples had silver concentrations of less than 6×10^{-12} g/ml with a mean concentration of about 2.5×10^{-12} g/ml. It was also found that, even at these low concentration levels, only 5% of the samples were contaminated during sampling and handling. Contamination of the northern control area by silver from adjacent seeded area was confirmed. The horizontal dispersion of seeding material observed in precipitation was wider in cases of cloud-top seeding than cloud-base seeding with the exception of two cases. However, in these two cases, environmental winds played a major role in dispersing the

seeding material; also, such winds likely have their greatest effect on material dispersion when seeding is carried out around the base and the outside perimeter of a growing storm. An insufficient number of large clean hailstones was collected to draw any conclusions on the location of highest silver concentration within a hailstone. It was observed that hailstones collected within the area of seeding generally showed higher concentrations of silver on the outer surfaces than did stones collected beyond the immediate seeding area.

The Evaluation program progressed in its study of past and current data and in its search for evaluation measures. The areal distribution of loss-to-risk ratios observed in Alberta between 1938 and 1974 was studied using the reparameterized beta distribution and likelihood ratio tests. Loss-to-risk ratios were found to be significantly smaller in the target area (Three Hills area) than in the control area (the rest of the Province) between 1960 and 1967 but the reduction may not be a result of the cloud seeding performed during that period. The inherent problems of the measure used and the existence of possible climatic influence preclude definite conclusions, but the finding does encourage conservative optimism. Further evidence from other measures will be needed to more exactly determine seeding effects.

Some preliminary statistical tests were also made on the impact energy data obtained in 1974 and 1975 from hailpad analysis. The two-parameter lognormal distribution and the gamma distribution were used. The gamma distribution appeared to give a better fit to the data than the lognormal. Seeded and non-seeded cases were compared for each year, and the year to year variation of both the seeded and the non-seeded cases was also studied. Natural variability of the data from year to year was considerable. Further refinements in selecting seeded and non-seeded hailpad samples will be needed to obtain more meaningful results. Such refinements may include considerations of pad locations, storm paths, and other factors affecting the representativeness of the hailpad samples.

Attempts were made to correlate storm model output data to observed hailfall measures. Significant relationships represented by high correlation coefficients (>0.8) were found. More tedious data reduction work is needed to provide the basic samples for seeded versus non-seeded comparisons.

Other measures for evaluating the hail suppression experiment of the AHP have been tested. Hailcard reports were used for measuring the length of hailswaths and the area of coverage of hailstones of different maximum sizes. Such measurements, combined with hailstone size distributions obtained from hailpads, permit the computation of the total hailfall impact energy. Hailswath lengths, hailfall areas of given hailstone diameters, and total hailfall impact energies were compared for seeded and non-seeded cases of 1974 and 1975.

In addition, such data permit the calculation of a severity ratio similar to that used in South Africa. In Alberta, the severity ratio is defined as the ratio of the areal coverage of large hail to the areal coverage of the total hailswath. The comparisons of data from 1974 and 1975 seed and no-seed cases suggest that these new measures may prove extremely useful in the evaluation of the hail suppression experiment.

During the winter, the manufacturer reclassified the computer system as a PDP-11/50 to accurately represent the hardware configuration. Also, a new operating system (RSX-11M) was purchased and installed to provide enhanced support and compatibility with other computers planned for the Alberta Research Council.

Further computer system hardware expansion through the summer included more high speed memory, a double-density magnetic tape drive, and two

interactive terminals. Software development included device-independent graphics support and asynchronous hard copy graphics generation.

At the request of the Air Quality and Meteorology Technical Research Committee of AOSERP, senior staff of the Radar Studies Program completed a study on the Feasibility of a Weather Radar near Fort McMurray, Alberta.

5. The University of Calgary - Departments of Physics and Geography

Research in Meteorology and Atmospheric Science is conducted at the University of Calgary in the departments of Physics and Geography. The focus of the activities is the boundary layer above the City of Calgary and the surrounding country. The objective is the understanding of the temperature and pollution fields within the city and the relationships between these fields and atmospheric structure under a variety of weather conditions. The effect of the chinook on these fields is of special interest.

(a) Acoustic Sounding

A programme to study the physics of the lower atmosphere and features such as clear air turbulence, stratifications, inversions, wind and temperature profiles using acoustic sounding is currently in progress. The technique employed consists of transmitting short bursts of acoustic energy and detecting the back-scattering of the acoustic signals with sensitive microphones. Turbulent layers and temperature discontinuities are the causes of back-scattering of the acoustic signal. By monitoring the signal strength, frequency shift and time delay, details of the turbulent layers can be studied.

Operation of a monostatic acoustic sounder on the campus of the University of Calgary for the period March to September, 1976, has provided data on the atmospheric boundary layer over Calgary. The formation and dissipation of the nocturnal temperature inversion layer leaves a clear signature in the sounder records. A trend is discerned in which the nocturnal layer tends to form at sunset, whereas convective instability is established some 2 - 3 hours after sunrise. Comparison of sounder records with an extensive set of radiosonde temperature profiles has shown that the height of the inversion layer can be determined reliably when a single, dark, ground-based return is visible on the sounder charts. On many occasions, however, the sounder detects multiple structures in the atmosphere. In these cases, it is difficult to establish a systematic correspondence of the turbulent structure as observed in the sounder records with the temperature profile as observed by the radiosonde.

Work is in progress to operate three sounders in Calgary so that spatial correlation of principal features over the urban boundary layer can be examined. Work also is in progress to examine how inversion heights determined by the acoustic sounder techniques can be used to improve an air column trajectory pollution model of the City of Calgary.

(b) Atmospheric Transmission and Visibility

A nephelometer has been constructed which will enable local air to be monitored for aerosol scattering. A visible region spectrometer views the scattered radiation thus facilitating the study of wavelength dependence of the scattered radiation. Simultaneous observations of atmospheric visibility are correlated with the nephelometer measurements. It is proposed to augment this work with a modulated c.w. laser probe for atmospheric transmission measurements which should overcome some of the difficulties encountered with conventional atmospheric transmissometers.

(c) Boundary Layer Meteorology

The series of experiments being conducted by the Department of Geography are designed to enhance our understanding of the atmospheric boundary layer over the city and the surrounding district and the temperature and pollution fields inside the layer. A network of stations has been set up to measure temperature, wind and pollutants in the study area. Two of the stations report profiles of wind and temperature up to 300 metres.

The temperature field at street level is marked by two hot pockets and two cold ones. The intra-city heat differential exceeds the urban-rural contrast. The average diurnal distribution of heat island intensity reveals a primary peak around midmorning and a secondary one just before midnight. The intensity of the differential is abnormally high under chinook conditions. These qualities of the island are related to urban fabric, topography, windfield, anthropogenic heat release and boundary layer thickness.

The nocturnal pollution field is stratified. It is homogeneous under adiabatic conditions. High concentration and 'abnormal' distribution of pollutants are associated with chinooks.

The experiments are continuing. Eventually we should be able to construct a predictive model for the two target fields based on easily measured parameters.

1975 saw the completion of a phase in our agro-meteorological work. A model was developed for assessing actual evapotranspiration from a crop from potential evapotranspiration and wetting frequency.

We also conducted a study of wet and dry sequences in the temporal distribution of precipitation in Alberta. The Gamma distribution was used. The results of the simulation were moderately good. The parameters of the distribution were used to demarcate mutually exclusive precipitation regions for the province.

6. Western Research and Development Ltd.

Western Research & Development Ltd. has continued to supply meteorological consulting services to industry and government over the past year.

(a) Industrial Clients

Two meteorological towers were established during the past year to collect wind, temperature gradient and turbulence data. One of the towers is in the foothills of Alberta while the other is on the MacKenzie Delta. Plans were finalized for the erection of two meteorological towers in the region of west central Alberta.

Climatological and air quality studies were conducted relating to: three proposed thermal power sites, urban expansion in Calgary, industrialization of Fort Saskatchewan, generation of cooling pond fog, plume dispersion in a mountain valley, and pipeline ruptures. Numerous routine diffusion calculations were performed in order to evaluate proposed stack designs.

Forty air quality measuring stations with WR&D manufactured wind measuring devices were maintained throughout southern Alberta.

(b) Government Clients

A detailed theoretical study of plume diffusion in the Alberta oil sands area was undertaken for a wide range of assumed meteorological conditions.

Studies concerning air pollution modeling for Calgary and Edmonton were completed. An examination was initiated into the influence exerted on Calgary's air quality by mountain generated wind systems. Consultation continued into the air quality implications of urban industrialization.

7. Saskatchewan Research Council

In addition to ongoing projects such as the Quill Lake Basin hydrometeorological study and the pesticide spray drift research which were described last year, SRC recently undertook special investigations of small agricultural watersheds for their water budget characteristics. The study when completed will provide methods to predict peak and total flows and depression storage. The results will be used to assess wetland drainage effects on farm land flooding. A study on climatic factors affecting lake water balance since the last glaciation has been commenced as well.

The relationship between heating degree days, solar energy input and natural gas consumption has been under study this past year. This is being undertaken as one facet in the design and construction of a demonstration house using solar energy for partial supply of heating needs on the Prairies.

Air pollution studies were continued, particularly into aspects of ambient grain dust levels and their possible relationship to farm-related living conditions. Investigations into specific SO_2 and sulfate particle levels in several local situations were also carried out. Techniques for identifying silver iodide particles in air samples were investigated, as one stage in the study of possible downwind effects of cloud seeding operations in Alberta and North Dakota. To date, several highly sensitive analytical methods have been found promising.

8. The University of Windsor

(a) Department of Geography

(i) *Solar and Net Radiation - Essex County*

Continuous measurement of incoming global solar radiation has been continued at the U. of Windsor and Pelee Island, and of net radiation at Pelee Island. Preliminary comparisons of urban-rural radiation have been carried out.

(ii) *Arctic Radiation and Energy Budget Studies*

Arctic programs during 1976 included fieldwork in Eastern Baffin Island to obtain micrometeorological data and information on local terrain and ice conditions. A 6 year program of studies of fast ice breakup processes in collaboration with the Institute of Arctic and Alpine Research (Colorado) is in the final stages.

(iii) *Precipitation Quantity and Quality*

To study the effect of the large metropolitan area of Windsor-Detroit on precipitation, a network of 18 recording precipitation gauges is being maintained in Essex county and a preliminary analysis of data is in press.

In connection with the PLURAG (Pollution from land use activities reference group) studies for the International Joint Commission, 10 additional recording precipitation gauges are maintained in southern Ontario. At 6 of the locations, CCIW type bulk precipitation samplers are located and precipitation analyzed for chemical content as well as PCB's and pesticides.

(b) Department of Physics

Controlled electron impact is being used as a tool to study the structure, fragmentation patterns and probabilities of excitation and ionization of many atmospherically important molecules. A particular study is being made of the freons in view of their significance in connection with the ozone layer.

9. The University of Western Ontario - Department of Geography

The Macrogeographic Systems Research Workshop is conducting research into broad aspects of the global climate. Global pressure surfaces have been analyzed as networks of critical elements for the description and prediction of flows. Continuing research centers on the use of potential measures as illustrations of continentality and their relationship to global temperature regimes.

10. The University of Waterloo - Environmental Fluid Mechanics Lab

Parameterized convective precipitation and fluxes of heat and moisture over water surfaces in winter are being studied to predict snowfall to the lee of the Great Lakes and east coast cyclogenesis, both off North America and Asia (using AMTEX data). The procedures are being tested with an 8-level primitive equations model which also includes large-scale precipitation and release of latent heat, long-wave radiation from clouds and water vapor, orography, and surface and internal friction. Predictions have been made for 6 to 36 h with grid distances varying from 47.5 to 190 km. The model has also been applied to large scale summer rainstorms in Alberta.

Low-level winds are being investigated using data from the Atmospheric Environment Service's meso-meteorological network over metropolitan Toronto. A one-level primitive equations model has been designed to compute local effects of topography on surface winds. Grid sizes of 2 to 20 km have been used. The model can simulate phenomena such as land and sea breezes, upslope and downslope winds, orographic channelling and influences of frictional convergence and changes in atmospheric stability.

A study of the heat balance at the earth's surface is underway. Thus far the wind has been assumed given so the sensible heat flux is known a priori. This investigation has applications both to boundary layer processes and tropospheric weather systems.

Research projects relevant to air pollution are and have been in the following areas:

(a) Diffusion in the Planetary Boundary Layer.

(i) Physical modelling of the friction layer (Laboratory model).

(ii) Full-scale measurements of cross-wind shear effects on the diffusion of plumes from tall stacks. This work was conducted at two sites in 1976, Sudbury, Ontario and Cartersville, Georgia. Aircraft sampling of the plumes and documentation of meteorological parameters were made.

(iii) Photographic and Lidar measurements of plumes from Ontario Hydro's Nanticoke Power station were made during 1976 and are presently being analyzed.

(b) Waste Heat rejection and environmental impact

(i) Computer models have been constructed and used to evaluate the environmental impact of Natural and Mechanical Draft cooling tower plumes and drift droplets.

(ii) Work is continuing on mathematical and physical full-scale models of plumes from waste heat rejection systems. Two field studies were carried out in Alabama in 1976 and a water tunnel modelling program is also underway.

Theoretical studies of the behaviour of flows containing suspended particulates or droplets are also in progress. The specific problem of acoustic wave propagation through atmospheric fogs has been analyzed in detail, and theoretical predictions are in good agreement with experiment.

11. McMaster University - Department of Geography

(a) Energy balance studies in the Canadian subarctic and tundra have been continued for the sixth consecutive year. These have centred most recently on the microclimatic changes which accompany burning in subarctic open woodlands. Considerable success has been attained in developing a simple evaporation model which is applicable in a wide range of northern environments.

(b) Radiation balance studies under conditions of heavy aerosol loading are also being continued with particular attention being given to infrared flux divergence.

(c) Global radiation and cloud transmission. A global radiation model, developed during IFYGL, is being evaluated and developed further using other Canadian data and data from GATE.

(d) Inter-surface variations in evaporation losses. Microclimatological data collected during the growth cycle of a soybean field are being used to compute evaporation rates and the aerodynamic and physiologic resistances. Various forms of the combination model will be examined.

12. The University of Toronto

(a) Department of Geography

(i) The effect of vegetation on the hydrology of a mixed agricultural watershed in southern Ontario. This work is done to supplement snowmelt studies in the same area by the AES.

(ii) Snowmelt and evapotranspiration in a forested watershed in the Ottawa Valley. In the winter particular emphasis is placed on the transfer of long-wave radiation in the forest, and how this features in the energy supply for snowmelt. In the summer the stomatal behaviour of the trees will be measured to establish their quantitative importance in transpiration and pollutant uptake. This work is done at Perch Lake, Chalk River (AECL) to complement the existing hydrological studies by Atomic Energy of Canada.

(iii) A dynamic model of crop growth as affected by climatological variables is being assembled. When ready, the model will predict crop yields as a function of weather and climate.

(b) Department of Physics

(i) *Cloud Physics*

A new theory on the heat and mass transfer of hailstones was tested on the basis of rotating cylinders. It could be shown that the heat balance is controlled by the temperature and ice content of the particles which are shed from the icing objects. Heat transfer measurements with rotating spheres were continued.

The modelling of the warm-rain process has considerably expanded our understanding of this mechanism. Further breakup experiments will help to increase the reliability of the modelling.

Insight into the free fall of disks was gained by having the particles followed by a falling high speed camera. The possible motions were found to be: oscillation, rotation about horizontal major axis, and gyration.

(ii) *Acoustic Doppler Sounder*

Echoes from falling snow were used to derive acoustic multiple scattering. The validity and usefulness of the newly applied Doppler technique was studied and demonstrated on the basis of statistical effects.

(iii) An experimental setup combining a mobility analyzer and mass spectroscopy with a quadrupole mass filter has been adapted to the study of ions produced by evaporation of charged droplets and is being used to determine the nature of these ions.

Experiments on gas-to particle reactions proceed with two gaseous systems: $HCl-NH_3-H_2O$ and $SO_2-NH_3-H_2O$. Nucleation curves are obtained with and without the presence of ions, showing the catalytic action of ions on these reactions.

A series of experiments is being finished on the capture of ions from unipolar atmospheres in an electric field by ice crystals, water droplets and models representing different shapes of ice crystals. The results are relevant to the formation of screening layers in thunderclouds.

A theoretical model is being developed to study numerically the formation of space charges below the base of thunderclouds.

(iv) *Wave Mechanics of Boundary Layer and Mesoscale Phenomena*

A resonant instability of boundary layer shear flows has been discovered which is based upon the multiple over-reflection of internal waves. The effects of dissipation upon the mechanism has been investigated and its influence shown to be negligible. An investigation of the finite amplitude evolution of Kelvin-Helmholtz and resonance modes has been completed.

A theory has been constructed for squall line initiation based upon the emission of internal waves during the frontal collapse process. A case study of squall line initiation has been completed using data from the 1966 NSSL field season which appears to support the theory.

A study of the finite amplitude evolution and stability and Lee waves has been completed. On the basis of this work a new theory for the origin of Chinooks has been postulated. This theory is based upon a

self amplification mechanism which is triggered when the wave field develops an internal convective instability.

(v) *Gravitational Interaction Between the Earth and its Ice Sheets and Oceans During Climatic Change*

The fully self-gravitating visco-elastic earth model described in the last bulletin has been successfully employed to predict the temporal history of raised beaches (C^{14} data) at a large number of points on the earth's surface. The model has been expanded considerably to include self-gravitating oceans and is being employed to study additional characteristics of the climatic change process.

(vi) *Numerical Simulation of Laboratory Convection*

This study is aimed at developing efficient and accurate numerical methods for the purpose of simulating atmospheric sub-grid processes. The numerical simulations are compared with the laboratory results. It is felt that since in the atmosphere subgrid processes cannot be measured directly, the algorithms developed should first be tested and verified against laboratory results.

(vii) *Regional Climate Anomalies*

The research is aimed at identifying the physical processes which maintain prolonged climatic anomalies such as a drought or excessive rainfall. The study is concentrated in areas where the variability is already very high. Such areas are the Arctic tree line and the desert margins.

(viii) *Numerical Methods for Obtaining Temperature Field From an Observed (Small Scale) Wind Field*

The study is aimed at determining the feasibility of deducing temperature and pressure fluctuations from non-simultaneous observations of the wind. The scales of motion that are of interest are the thunderstorm scale and below. Thus none of the conventional methods work.

(ix) *Zonally Averaged Energy Balance Models*

This project is described in last year's issue. It is a continuous development of "simple" climate models capable of simulating "large" climatic changes (e.g. ice-ages). They are particularly useful in simulating climatic changes which are global in their extent.

(x) Progress has been made in the following areas during the past year.

- Representation of cloud life-cycle effect on the large-scale heat and moisture budget equations.

- Statistical structure of equilibrium cloud field.

- Interaction between cloud layer and the subcloud mixed layer.

- The effects of moist convection in the process of air mass transformation.

13. York University - Department of Physics

1. Field Observations

(a) Long path high resolution observations of atmospheric absorptions, specifically

(i) $C\ell O$ absorption from the stratosphere.

(ii) High and low resolution observations on the spectrum of daylight in the Toronto area to establish a data base for use in remote sensing and, possibly, solar power.

(iii) High resolution and low resolution observations of brown haze over Toronto.

(b) Measurement of droplet concentrations and size distribution in thin layer brown haze over Toronto and correlation with atmospheric parameters.

(c) Monitoring summer tropospheric aerosol and atmospheric contaminants over Greenland and the North Atlantic Ocean (in collaboration with Danish Atomic Energy Commission and the Université Paul Sabatier, Toulouse).

(d) Correlation of concentrations of Aitken nuclei, cloud condensation nuclei and freezing nuclei with meteorological conditions.

(e) Ground based spectral measurements (0.45 to 0.75 micrometres) of global and diffuse solar radiation have been made in conjunction with a Landsat 11 overpass and an airborne photometer overpass in an effort to develop methodology to determine atmospheric-backscattered radiance corrections for satellite imagery. These data are being used in the assessment of two methods of computing the backscattered radiance component from ground-based global/diffuse measurements.

(f) Laser propagation and scattering measurements in the atmosphere. Lidar sounding of atmospheric properties with our mobile ruby laser radar facility. Two wavelength operation of lidar with polarization diagnostics for aerosol, cloud and precipitation studies. Lidar tracking and profiling of smoke plumes for dispersion studies.

2. Laboratory experiments

(a) Establishment of the structure constants and transition probability data for atmospheric molecular spectra, particularly the A-X transition of $C\ell O$, O_2 and O_3.

(b) Study of spectral distribution of light scattered from thin layers of monodisperse droplets and spheres (with reference to the formation of thin layer brown haze).

(c) Study of condensation and inhibition of condensation on soluble and insoluble particles.

(d) *Development of Instruments*

(i) A cloud condensation nuclei counter based on continuous expansion.

(ii) A low pressure freezing nuclei counter.

(e) *Aerosol Light Scattering Measurements*

Scattering for aerosols and water droplet fogs using laser sources (HeNe @ 623 nm, Argon @ 514 & 488 nm and the tunable dye lasers in the 450 to 600 nm range). Angular scattering studies, single and multiple scattering in dense clouds and fogs. Polarization characteristics for ice-water discrimination. Tuned resonant absorption measurements of gaseous pollutants.

3. Theoretical

(a) Application of computer-generated high resolution synthetic spectra in the study of

(i) Atmospheric absorptions in support of the strataprobe balloon programme.

(ii) Atmospheric absorptions in support of our own ground based measurements.

(iii) Absorption properties of various atmospheres of CO_2 in the 4.3 micrometre band.

(iv) Interpretation of laboratory and astronomical spectra.

(b) Theoretical studies on the reflection spectra of real-world surfaces.

(c) Development of one and two dimensional time dependent photochemical and dynamic modelling of ozone depletions due to anthropogenic pollutants.

(d) Image reconstruction of stable auroral red arcs - Tomography.

14. Trent University - Department of Geography

The programme of snowfall and snowcover studies continued as did the study of ice and snow on lakes in central Ontario. A study of snow gauges was initiated and an analysis of the climatological record of Peterborough was brought close to the publication stage.

15. National Aeronautical Establishment

Early in 1974 the NAE Flight Research Laboratory entered into a cooperative program with the Forest Fire Research Institute and the Cloud Physics Research Division of the Atmospheric Environment Service, to determine the potential of using weather modification as a means of enhancing rainfall. The proposed application of the project is the control of large forest fires by inducing precipitation from cumulus clouds either advecting with the wind towards the fire or developing over the fire because of local heat and water vapour input. Other possible applications of successful weather modification techniques are hail suppression to reduce crop damage and rainfall enhancement for agricultural purposes and hydro-electric power generation.

During the summers of 1975 and 1976 cumulus cloud seeding experiments were conducted at Yellowknife, N.W.T. Three NAE aircraft were used during the 4-week 1976 experiment. The T-33 atmospheric research aircraft seeded selected towering cumulus clouds and measured turbulence levels, fluxes, and energy dissipation rates during the cloud penetrations. The Twin Otter served as command aircraft and conducted extensive microphysical measurements within the clouds before and after seeding. A Beech 18 was flown beneath the target clouds to monitor precipitation.

16. MacDonald College - Department of Agricultural Chemistry and Physics

Plant-environment interactions were studied by using a closed-circuit wind tunnel and a microwave energy source. A simple mathematical model was built to determine microwave energy absorption by biological specimens. Attached bean and water hyacinth plants responded to thermal stress, induced by microwaves in darkness, by lowering equilibrium leaf temperatures from 2 to more than 10 C^{o} in still air.

Controlled laboratory experiments have led to reproducible results which indicate that small air ions can affect life processes. It was found that small positive air ions (1×10^{5} ions/cc concentration) significantly reduced the number of lesions and percentage of leaf area covered by lesions of net blotch disease of barley. No such effect was observed for negative air ions. Height and dry weight were significantly stimulated by unipolar air ions.

In 1976 field experiments on heat transfer and evaporation from ground-based surfaces in different types of vegetation were completed. The results agree (with a standard deviation of 25%) with predictions made on the basis of a model derived previously from electrochemical model experiments. Preliminary reports were presented to meetings of the Canadian Meteorological Society, American Society of Agricultural Engineers and to a joint meeting of the Swiss Geophysical and Meteorological Societies and the American Meteorological Society on Mountain and Bio-Meteorology.

A study of the thermal microclimate within a corn-plot and its development through the growing-season, was continued, making use of daily maximum and minimum air temperatures at various heights over short grass (at a standard climatological site) and within a nearby stand of corn. During the summer (1976) the corn microclimate was successfully modified by means of cultural intervention (judicious thinning), thereby reproducing results obtained during three prior summers.

17. McGill University - Department of Meteorology

(a) Numerical experiments have been performed to study the structure of orographically forced planetary-scale waves. The emphasis was placed on the minimum model resolution required in the vertical to represent the important features of the waves. The horizontal propagation of large-scale waves from a source region in the middle latitudes towards the low latitudes was also examined by means of a numerical model.

The testing of a one-dimensional semi-implicit scheme as a replacement for polar filtering has been completed and found to be superior in both the one and two layer pseudospectral model. Further experiments on the effect of numerical filtering are in process.

(b) In 1976 work continued at McGill in energy balance climatology and climatic impact studies, carried out by computer model simulation. A number of papers appeared in the meteorological literature and in Research Reports, as well as in the form of graduate degree theses.

18. Ministère des Richesses Naturelles du Québec - Service de la Météorologie

En 1976, le service de la Météorologie du Québec a poursuivi la plupart des programmes d'études déjà entrepris et décrits dans les volumes précédents du "Bulletin canadien de géophysique". En particulier, l'accent a été mis sur les projets suivants:

(a) Programme de Connaissances intégrées

Le service de la Météorologie a terminé l'étude hydrométéorologique du bassin de la rivière Saint-François, laquelle sera publiée en 1977, et a entrepris l'étude hydrométéorologique du basin de la Yamaska.

(b) Projet de rationalisation du Réseau météorologique

Il s'agit des étapes préliminaires à une étude plus complète. Ces étapes préliminaires comprennent une étude des besoins régionalisés du réseau, de la précision requise pour répondre à ces besoins et d'une étude d'homogénéité des séries chronologiques de données.

19. Bedford Institute of Oceanography, A.O.L.

In May 1975, the Science Procurement Branch of Department of Supply and Services funded, on behalf of the Department of Environment, Phase I of a broad ranged program to investigate the use of ocean data buoys. This was within the "Make-or-Buy" policy, the program being proposed by Hermes Electronics Ltd. of Dartmouth, Nova Scoita. The scientific management was assigned to the Atlantic Oceanographic Laboratory of Bedford Institute of Oceanography.

Phase I covered a review and design study of various systems of a data buoy and a detailed review of future requirements of both Government and industrial users. It also allowed for the construction and testing of a limited number of hull forms with instrument packages together with a short-range data transmission link to shore.

Final testing in the fall of 1976 was a comparison between buoys and their sensors and a known reference. The reference was the B.I.O. Stable Platform which carried an Atmospheric Environment Service Instrumentation suit capable of monitoring wind speed and direction, temperature and pressure. Each buoy, moored close by the B.I.O. Tower, carried a selection of sensors and these data, including motion records of each buoy, were transmitted to a shore station. Within the same test area a torroid buoy, presently used by Canada Centre for Inland Waters, and a conventional 4-ton Yacht Hull, designed and fitted out by B.I.O., were moored. Each of these hulls was equipped with motion and wind speed/direction sensors. The results of this multi-buoy test are being analyzed.

Within Phase I, various types of drifting buoys, capable of transmitting data to a satellite, were also investigated. Two different hull forms were built and tested for survival condition and an acceptable design evolved. Several buoys of this design, together with an on-board instrumentation package capable of recording sea temperature and air pressure are presently undergoing ocean testing. Their data are relayed via the Nimbus satellite. It is hoped that this design will meet the A.E.S. international commitments.

Phase II commenced in November 1976 under finance from Atmospheric Environment Service, Ocean and Aquatic Sciences, Ministry of Transport and National Research Council; starting April 1977, N.R.C. will become the lead agency involved. This program will further test the existing equipment and its ability to meet requirements for scientific and operational users. It will also provide a prototype system for industrial users. Analysis and review of the forementioned Phase I test will continue.

20. The Atmospheric Environment Service

(1) Meteorological Service Research Branch

(a) *General Program*

The Meteorological Services Research Branch is organized to provide support for the expansion and improvement of the forecast services of the AES. This organization includes an effort in support of redesigning the basic AES operational environmental observing and forecasting system to make it more efficient mainly through inclusion of advances in technology such as those in the area of remote sensing from weather satellites and an increasing degree of automation of Canada's operational forecasting function. The basic program of the Branch is one of applied research including some more fundamental aspects where necessary. In total, the program brings together 'mission-oriented' research covering a rather broad spectrum of development, application and engineering-test-implementation studies in the following areas.

Large-scale dynamic prediction in numerical atmospheric modelling and development of atmospheric forecast systems.

Operational forecast research dealing principally with the process of deriving user oriented forecasts of weather elements from twice-daily large scale predictions and continuous local or regional information.

Prediction of environmental phenomena which are in large degree controlled by the weather such as atmospheric pollution, wind-waves and ice at sea or on inland waters.

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

Design of integrated automated systems for producing forecasts entirely by computer, right from recognition of all data including the latest, through large scale NWP, through more regional and local processes complete to the final forecast products and to systems for their distribution and access to them.

Observational network design test system is the title of a system, design of which proceeded to the first operational runs, to carry out a new program to provide quantitative answers on major changes that could be made in Canada's meteorological observing networks. This information will be an important factor in the future decisions that the Service will continually be making in the development and operations of its costly observational networks.

Balanced programs in all the above areas are either taking shape or are well underway and all will be well-developed within the next couple of years. Current projects and interests are described below and are designed to fit in with one evolving general program.

(b) *Specific Areas and Studies*

(i) The spectral primitive equation model described in last year's report was implemented operationally in February 1976, with a rhomboidal resolution of 20 waves. Development is continuing, both the physical and numerical formulation, and more refined versions will be implemented in 1977.

(ii) Work is well underway on the formulation of the 4-dim. data assimilation by optimum interpolation for spherical geometry. This will be more convenient operationally and will also facilitate the assimilation of global data from FGGE.

(iii) Work progresses on the formulation of a model by finite elements. This year, the use of these functions for the vertical representation was tested successfully.

(iv) Installation and performance evaluation of a computerized prediction support system for the Beaufort Sea and adjoining areas has been successfully completed. A more advanced system is now being planned for the five other weather centrals in Canada. Before the installation of each Regional system, an advanced prototype will be run and tested at the Meteorological Services Research Branch new weather office simulator.

(v) In support of development work for the computerized prediction support system, an Historical Data Access System (HISDAS) for operating and testing Regional update models and generating predictor sets for weather element and weather-dependent environmental prediction procedures has been developed. The data access system has hourly values of all data and fields used in Regional prediction.

(vi) Development continues on Regional modelling with boundary information supplied by large scale models and by the latest hourly and asynoptic data such as vertical temperature profiles from satellites.

(vii) Real-time testing of the 7-level physical-dynamical planetary boundary layer prediction model is continuing. (see 1975 CGB)

(viii) The Small Area Model (see 1975 CGB) was used operationally to predict surface winds in connection with the 1976 Beaufort Sea drilling operations. It is also being used on a quasi-operational basis at the Atlantic and Pacific Weather Centres.

(ix) Development continued on physical-statistical procedures for automated prediction of weather elements. The statistical procedures use physically significant meteorological and geophysical parameters.

(x) Data-resource development has continued and computer accessible files of weather information have been developed for the Beaufort Sea area for the summer of 1975 and for the Ontario area for the summer of 1976.

(xi) Development continued on the three-dimensional trajectory model to track air parcels for forecast periods out to 24 or 36 hours. (see 1975 CGB). The prospective operational version of the model for weather element prediction is being tested with both real and idealized data, and seems to be mostly satisfactory.

(xii) An observational network test system was designed, development almost completed and will be used to determine the effects of adding or removing stations, and on the impact of various configurations of observational facilities.

(xiii) An automated real-time radar-echo prediction procedure (0-3 hours) was run for 6 months in the summer of 1976 by McGill University under contract for MSRB. The evaluations of the

forecasts are currently being carried out by McGill and the Quebec Region.

(xiv) The Aeromet Experimental Facility in Woodbridge has been completed. Measurements of wind and turbulence structure in the planetary boundary layer are being carried out using the fifteen 10-meter towers and one fifty-meter tower which comprise the facility. A wind tunnel model of the site has been completed and is awaiting testing. Comparisons of full scale and wind tunnel data will be performed for the purpose of evaluating the validity and faithfulness of wind tunnel simulation techniques currently in use.

(xv) Field measurements at a typical urban STOLport have been carried out in support of an MOT investigation of wind effects on the handling characteristics of STOL aircraft during landing and take-off. A wind tunnel model of this STOLport has also been constructed and will be used in an attempt to simulate in the laboratory the winds measured in full scale.

(xvi) A data processing facility is being developed for a variety of meteorological satellite data processing functions such as: geometric and radiometric correction, image registration, image enhancement, applications research and archiving of satellite data.

(xvii) A program is underway to produce absolute thermal radiation flux maps of the earth's surface. These maps would incorporate a correction for atmospheric effects. The results have a broad range of applications, including east and west commercial fishery, effluent detection and monitoring in areas such as the Great Lakes, small area modelling and hydrological energy balance modelling.

(xviii) Investigations are being carried out into the effects the earth's atmosphere has on outgoing radiation, the objective being to make corrections to satellite derived measurements for these effects, particularly, water vapour and aerosols.

(xix) The application of satellite derived measurements to several problems is being attempted. Among them: hydrological energy balance studies, climatic change, snow and ice cover mapping.

(xx) The Satellite Data Laboratory of the Aerospace Meteorology Division continues to acquire direct weather satellite data from U.S. meteorological spacecraft. Visual and thermal Infra-red data from the Very High Resolution Radiometer (VHRR) system of the NOAA series of weather satellites is acquired by "S" Band receiving equipment direct from the orbiting spacecraft and digitized for computer processing and the output of imagery for operational and research uses. Processed data suitable for national facsimile circuit transmission is distributed to major weather centres in near real-time to produce high quality photographic imagery at each of the centres equipped to receive it. Data are sent out from both day and night-time orbits approximately every twelve hours. Special ice and other types of full resolution and enhanced satellite imagery are distributed by dialed broadband telephone circuits to specific users such as the Ice Forecast Centre in Ottawa.

Meteorological Infra-red and visual imagery from the GOES series of geostationary weather satellites is directly acquired

from the WEFAX transmission system. Early in 1977 "GOES-tap" data, acquired from the Visual Infra-red Spin Scan Radiometer (VISSR) of the GOES spacecraft and centrally processed and sectorized by U.S. Data Utilization Station for landline distribution, will be available in the laboratory from a landline drop on the "GOES-tap" trunk circuit at Buffalo. This will make available sequential satellite coverage at approximately half hour intervals in both visual and infra-red modes day and night for storm tracking applications and research in support of forecasting system development.

(2) Atmospheric Processes Research Branch

(a) *Cloud Physics Research Division*

Cloud Physics/Weather Modification Program

The joint program, which began in 1974 in cooperation with the Canadian Forestry Service and the National Aeronautical Establishment to assess the potential of weather modification as a means of suppressing forest fires, was continued. During 1976, a three week cumulus cloud seeding experiment was conducted out of Yellowknife, N.W.T., using 3 aircraft within a cloud seeding/monitoring system. Eleven cumulus clouds were seeded using a total of 74 flares, each containing 50 gm of AgI. The data from these experiments, as well as those from 1975, are being intensively analyzed and should provide answers to many fundamental problems on weather modification.

No direct research activities were undertaken by the Cloud Physics Research Division in the Alberta Hail Project in 1976, however, a Weather Modification Workshop was organized which devoted one day to a discussion of ALHAP. Radiosonde observations at Rocky Mountain House, Alberta, were provided on a cost recoverable basis in 1976.

Cloud Modelling

Dynamics: Work on the Division's three-dimensional convection model continued to improve the level of sophistication employed to simulate cloud processes. The development of a practical method to simulate condensation and coalescence processes was the main object of the year's work.

Microphysics: A novel approach to the simulation of warm rain was developed. Fundamental studies on droplet collision processes continued. In addition, a new thrust in the study of ice particle growth and motion was initiated. This problem has a high priority and will be receiving increasing attention.

Radar Meteorology

Weather radar data were archived on film and magnetic tape on a 5-day per week program. Hardware/software development continued. The resolution in height and time of the recorded data was about doubled. Raindrop distribution data were collected throughout the rainy season. The variation in reflectivity, rainfall rate and drop distributions, their interrelationships and the effects of droplet growth are being studied. Coincident airborne drop distribution spectrometer data is also being used.

Atmospheric Electricity

Measurements of the continental sferics activity were made by a VLF analyser and its relationship with thunderstorm activity was

studied. Good correlations were observed for all seasons except winter. Potential gradient, air earth current density and polar conductivities were measured as the data source. Studies to investigate the biological effects of atmospheric ions were undertaken in cooperation with the University of Toronto and McGill.

(b) *Numerical Studies Division*

General Circulation Modelling

Design, programming and initial testing of the 5-level global general circulation model has been completed. Climatological simulations will proceed together with continued improvement of the physical parameterizations.

Parameterization of Sub-Grid Scale Inertial Processes

Subgrid scale inertial effects have been simulated, (assuming a non-local non-linear process) in a General Circulation model by a scheme called spectral shaving.

Parameterization of Wave Momentum Flux

A parameterization scheme for the vertical flux of wave momentum in 3-dimensional lee waves was obtained in terms of the convergence of horizontal heat flux. The theory on which this scheme is based has been verified from the data collected and reported by Vergeiner and Lilly.

Upper Boundary Condition in General Circulation Models

A theoretical analysis in a more sophisticated system of spherical geometry offers a practical method which selectively absorbs (in the uppermost layer of the G.C.M.) perturbations on those space and time scales which give concern when the upper boundary condition currently used does not permit upward propagation of waves leading to resonance due to false reflection.

Stratospheric Pollution Modelling

Steady state experiments have been carried out with the 2-dimensional stratospheric radiative-photochemical-transport model, to determine the impact of chlorofluoromethanes (CFMS) on stratospheric ozone distribution and temperature structure. Additional experiments are now being conducted to determine the ozone depletions due to CFMS in a 2-D time dependent model.

Two-Dimensional Climate Modelling

A two-level quasi-geostrophic model is being used to simulate the annual cycle of the General Circulation. The effects of eddy transports are parameterized by means of baroclinic stability theory.

One-Dimensional Climate Modelling

A version of the Sellers-Schneider-Gal Chen energy balance model has been used to estimate the climatic response to the greenhouse effects of freons. The model was extended to include abyssal ocean effect and the impact on model climate was investigated.

Spectral Diagnostics

Six days of G.A.R.P. data (every 100 mb from 950 to 50 mb) were analyzed with respect to vertical profiles of the spectral amplitudes and the governing power laws.

Probability Forecast Methods

Time series of climatic records are being analyzed, both in time and space, to provide further information on statistical characteristics of climate and for possible use in prediction. Time series analysis methods developed by G.E.P. Box and G.M. Jenkins are being tested in long range forecasting 500 mb height patterns.

Climatic Trends in the Northern Hemisphere

Mean temperature trends in the lower troposhere over the N. Hemisphere north of 25°N, are being studied for the period 1949-76.

Climatic Information and Prediction

A Climate Information and Prediction Systems Group (CLIPS) has been formed whose objectives are to develop climate monitoring and long range prediction techniques for application on an operational basis in due course.

(c) *Experimental Studies Division*

Stratospheric Measurements Program

Experimental studies of the stratosphere are continuing in the Atmospheric Processes Research Branch, in order to assess the effects that anthropogenic pollutants such as freons, SST's, and nitrogen fertilizers have on the ozone layer.

Results of the STRATOPROBE II balloon flights which were flown from Yorkton, Saskatchewan in August, 1975 have been analyzed. The vertical profiles of nitric oxide, nitrogen dioxide, and nitric acid were found to be much the same as the profiles measured during STRATOPROBE I from Churchill in July, 1974. Measurements of freon and N_2O were obtained from the stratospheric air samples taken during the 1975 campaign. The measured values of nitrogen compounds from STRATOPROBE I and II and the freon measurements of STRATOPROBE II are in good agreement with the nitrogen and chlorine photochemistry schemes assumed in stratospheric pollution models.

In 1976, two flights of STRATOPROBE III were flown from Yorkton in August. The payload configuration was similar to that of the chlorine configuration of 1975. Changes were the replacement of the GASPEC by the scanning NO_2 spectrometer and the addition of a UV flux meter to measure the absolute solar flux between 190 nm and 210 nm. Remote sensing measurements of ClO and HCl may have been achieved.

Ground based measurements of NO_2 and total ozone were carried out at Yorkton during the STRATOPROBE III operation. The NO_2 measurements were made with a spectrophotometer which is basically the same as the NO_2 balloon spectrophotometer. The ground ozone measurements were made with a Dobson spectrophotometer which was stationed at Yorkton for the balloon campaign.

Ozone

Daily surface-based measurements of total atmospheric ozone, made with the Dobson ozone spectrophotometer, continue at Churchill, Edmonton, Goose, Resolute and Toronto. The vertical ozone profile from the earth's surface to about 30 km is measured by balloon sonde each Wednesday.

Observational testing and development of the new ozone network spectrophotometer is continuing. The new instrument is being compared with the Dobson instrument and the performance of the new instrument is being evaluated. A contract has been awarded for the development of a commercial version of the new instrument.

Radiation

The National Atmospheric Radiation Centre (NARC) calibrated 116 radiometers during this period. An intercomparison of working standard radiometers was held at Mt. Kobau, B.C., during August. A special series of measurements of solar radiation on inclined surfaces was commenced in November at the Meteorological Research Station, Woodbridge, at the request of the Division of Building Research, National Research Council. A new ventilation device for pyranometers has been designed and constructed. The device is now under test and should prevent the accumulation of dew, rain, and snow on pyranometers. A new type Voltz sunphotometer has been constructed and preliminary testing gave satisfactory performance during calibration at Boulder, Colorado.

(3) Air Quality and Inter-Environmental Research Branch

(a) *Long-Range Transport of Air Pollution*

The AES portion of the DFE program on the long-range transport of air pollution will involve three components: the development of trajectory analysis and more advanced long-range transport modelling capabilities; the development of a network of stations to measure concentration and deposition of sulphur compounds; and supporting research on processes and techniques. A network of 40 precipitation chemistry monitoring stations is being installed across Canada. During August 1976, AES and EPS carried out a joint intensive study of daily concentrations of particulate and precipitation sulphate at 30 stations across Eastern Canada.

(b) *Alberta Oil Sands Environmental Research Program (AOSERP)*

Intensive efforts were directed toward the establishment of a meteorological data base for the Oil Sands area including the establishment of 10 climatological stations and a 500' meteorological tower, the testing of a mobile minisonde system and a study on the application of a balloon-tracking radar, the completion of the first intensive field study in March 1976 and the planning of the second field study in February 1977. Research projects were completed on air pollution potential climatology and the climatology of low-level air trajectories for the Oil Sands area. Additional research is continuing in pollutant transformation processes, pollutant deposition processes and the derivation of plume dispersion coefficients. Current modelling activities are focussed on the simple Climatological Dispersion Model and a literature survey concerning regional dispersion models.

(c) *Spruce Budworm Project*

The objective of the participation by the Branch in the field program of the New Brunswick Spruce Budworm Adult Dispersal Project was to determine the origin of mesoscale convergence features which had been observed to produce line-concentrations of spruce budworm moths over central New Brunswick. The field study utilized a special mesoscale surface observing network in Southern New Brunswick to collect data through June to mid-July and an atmospheric sounding program for the lowest one to two kilometers during the active moth migration period in late June and early July. Initial indications are that the only significant moth-concentration event observed during the 1976 field season was well documented by meteorological observations and that this particular feature can be traced back to the Bay of Fundy.

(d) *Measurement Techniques and Systems*

A system, consisting of a gas chromatograph with an electron capture detector, has been developed for the automated measurement of freons, other light halocarbons and nitrous oxide. A diffuse sky spectrophotometer has been developed to measure the radiance (300-500 nm) of the blue sky in Toronto. The experimental results are extremely important in assessing the potential input data for passive remote sensing devices which use skylight as a light source.

Development of a point monitor for nitrous acid, an important precursor in photochemical smog formation, using the principles of correlation spectroscopy is well underway. Particular attention has been paid to the design of the wavelength sampling elements for the spectrometer which will be specific to this particular pollutant.

A Kautsky Apparatus, which measures the fluorescence from chlorophyll in living plants, is nearing the end of construction. When this hand-held field unit is placed into contact with a leaf, the time decay of the fluorescent activity of the chlorophyll can be examined for the photosynthetic response of the plant. The device will be used to study air pollution damage on living plants.

Air sampling devices, using special filtering techniques, have been developed to measure sulfate particulate matter and sulfur dioxide in the same sample. Analysis of the filters by an isotope-dilution technique, has provided the sensitivity and accuracy necessary to measure background sulfur concentrations. This sampling method and analytical technique have been used in field studies at Sudbury during September to determine oxidation rates of sulfur dioxide in plumes.

The development of a polar nephelometer prototype, which measures the amount of light scattered by aerosols as a function of angle, is nearing completion. The measurements can be used to categorize the number of aerosol particles per unit volume of air sampled as well as the size distribution of those aerosol particles.

The tethered balloon system has been refined and was used during the AOSERP and the Spruce Budworm Experiments. An acoustic sounder system is being developed and a prototype was operated in AOSERP and the Spruce Budworm Experiments.

(e) *Atmospheric Pollutant Processes*

The oxidation of SO_2 to sulfuric acid and sulfates was studied at Sudbury during September of this year. Results from two different

sampling methods were used to validate the measured oxidation rates. Samples of particulate matter were also collected to measure the sulfuric acid and metal content of the INCO smelter plume at varying downwind distances.

A study of oxidants and their precursors in the Toronto area was carried out in the summer of this year at two sampling sites, Toronto Island and Maple. Continuous air monitoring for NO_x, O_3, and SO_2 was done during the summer months from June through October. In addition to particulate light scattering, particulate matter was collected on a daily basis for future analysis of sulfate content.

Two studies were done at Sudbury to relate the physical characteristics of the plume from the 380 meter smelter stack to the corresponding atmospheric structure. Time-lapse photographic observations of plume-rise and plume vertical dimensions were taken for comparison with simultaneous minisonde profiles of temperature and wind structure. Also, multiple correlation spectrometers (up to three) were used simultaneously at different distances downwind under the plume in order to study both the optimum methodology for SO_2 mass flux determinations and the variation of the horizontal dispersion coefficient with downwind distance. Attention was concentrated on periods of atmospheric stability and at the onset and during morning fumigations.

In the laboratory, a method is being developed to measure the ability of atmospheric aerosols to oxidize sulphur dioxide to sulphates. A special apparatus permits the exposure of aerosols to SO_2 at various concentrations and temperatures for selected time periods with subsequent analysis of the aerosol for sulphur uptake. Oxidation rates expected in the atmosphere will be derived from the experimental results and these will be applied to aerosols in polluted and "background" air as well as those in stack plumes.

The generation, build-up and dissipation of ozone levels across Southern Ontario are being investigated in relation to associated meteorological conditions. In particular, trajectory analyses are being applied to investigate the contributing effects of trans-boundary flows of photochemical precursors, large urban centres and lake-induced local circulations.

(f) *Air Pollution Effects*

The analysis of vegetation from remote areas, e.g., High Arctic, is currently in progress to obtain background values for various pollutants.

Another project is concerned with potential effects of changes in air quality on Arctic vegetation and, in particular, lichens which are of vital importance in this ecosystem.

For a review of the air pollution impact on vegetation in the Saint John Region, see the 1975 annual review, section 16(b) page 145.

As part of the AOSERP programme a study has been initiated whereby epiphytic lichens are being analysed for their heavy metal and sulfur content in order to define atmospheric deposition patterns around the local sources.

Research on plant injury by air pollution continued in 1976 toward the objective of developing quantitative relationships between plant injury and pollutant uptake, as determined by plant physiological response and environmental conditions. Criteria for the effects of

mixtures of air pollutants on horticultural crops are being developed under contract to the University of Guelph.

A workshop on Canadian research on development of Criteria and Standards for Air Pollutants is in the planning stage.

(g) *Air Quality Modelling*

A multiple-cell trajectory model has been used to calculate the concentration of nitrogen oxides in Toronto. Model predictions have been tested with data collected during field studies and satisfactory agreement has been obtained.

Mathematical models have been developed for treating dispersion and chemical transformations of reactive pollutants in chimney plumes. The models have been applied to predict oxidation of sulfur dioxide to sulfates in the plume of the INCO superstack at Sudbury, as well as nitric oxide to nitrogen dioxide in the Nanticoke generating station plume.

A model of SO_2 washout and redistribution in the atmosphere has been developed which utilizes a more accurate description of droplet-air exchange of SO_2 than has hitherto been used.

In order to define medium-range pollutant transport in the boundary layer, an air parcel trajectory model has been developed which derives representative winds from observed fields of surface pressure using an objective analysis technique for hourly data in a 31 x 28 grid system with a grid length of 127 km, and appropriate corrections for surface frictional effects. For final trajectories (back or forward time step), hourly wind vectors are integrated over periods up to 2-3 days. This model is currently being applied in studies of the source regions for photochemical ozone and for sulphate aerosol measured at Canadian monitoring sites.

For application to the long-range transport of pollutants, an operating three-dimensional trajectory model has been developed which will be used in the determination of the pollutant concentration fields using an emissions inventory for input. The model uses the objectively analyzed height, temperature and wind fields from the Canadian Meteorological Center history data base to compute backward or forward trajectory segments, time intervals and durations (currently 3 hour steps for up to 5 days). The model can operate anywhere in the Northern Hemisphere using data currently archived at the Canadian Meteorological Center.

(h) *Environmental Assessment*

Interactive computer programs have been developed for Gaussian plume models under unlimited mixing, limited mixing and fumigation conditions.

An air pollution potential climatology for Canada, in the form of an analysis of mean monthly, seasonal and annual values of maximum mixing height, wind speed and ventilation coefficient has been accepted for publication by "Atmosphere".

A study has been completed which examined the applicability of the Pasquill-Gifford stability classification scheme for Canadian conditions.

Reviews were carried out for two large air quality impact study reports prepared by consultants for Syncrude, Alberta, and for the proposed Afton Mine/Mill/Smelter, B.C.

A project has been undertaken jointly with the University of Toronto and National Research Council to instrument the CN Tower in Toronto to provide data for research in structural design. The four levels of wind speed and direction (maximum level 555 metres) and three of temperature (maximum level 415 meters) will also add to our knowledge of vertical variation in atmospheric structure. There are plans to install instrumentation to measure ozone, oxides of nitrogen, particulates and sulfur dioxide up to three levels, to delineate the vertical distribution of oxidants and other precursors of photochemical smog, in conjunction with a current study of horizontal variation in the Toronto area.

For a review of AES activities in the WMO Background Air Pollution Monitoring Network, see the 1975 annual review, section 16(b), page 145.

(i) *Hydrometeorology and Environmental Impact Research*

Measurement Techniques

The Hydrometeorology and Environmental Impact Research Division reported the results of the WMO Snow Studies by Satellite Project on the Saint John and Souris Basins. Basic imagery used in the analysis was NOAA/VHRR imagery received by the AES Satellite Data Laboratory in Downsview, enhanced to facilitate snow cover analysis. This was supplemented by LANDSAT I and III data for the period February to April, 1976. Snow cover analyses using conventional surface data only were compared to analyses based on both surface and satellite data.

The division has, for the past number of years, carried on a program to determine the performance of various precipitation gauges for the measurement of snowfall and snow samplers for the measurement of snowpack. The gauges used in the study are: M.S.C. Nipher Shielded Snow Gauge, Fischer and Porter Recording Precipitation Gauge, Universal Recording Precipitation Gauge, and the Tretykov Precipitation Gauge. Results indicate that the M.S.C. Nipher Shielded Snow Gauge gives superior performance.

Field studies were continued and a number of reports were written in support of the Working Group on Precipitation, Evaporation and Soil Moisture of the WMO (CIMO). In November the Working Group on Hydrology of the Canadian Advisory Committee on Remote Sensing (CACRS) and the Canadian Remote Sensing Society sponsored a Workshop on Soil Moisture and Groundwater.

A contract to study the energy balance of areas partly covered by snow was let to the University of Toronto.

Hydrometeorological Modelling

The division is involved in two hydrometeorological modelling projects. The purpose of the Large-Scale Water-Balance Project is to produce national maps which provide improved estimates of mean precipitation, evapotranspiration and runoff.

The WMO Saint John Basin WWW Project examines the present and potential applications of the World Weather Watch to operational hydrology. A computer program for determining daily areal precipitation by sub-basin has been developed for use with the SSARR

stream-flow forecast model. A progress report on the multi-agency international project was prepared for the meeting of the WMO Commission for Hydrology in Ottawa in July.

(j) *Boundary Layer Research*

Boundary Layer Structure and Turbulence

The continuing research in this area was reported in the 1975 annual review, section 16(b), pages 146-7.

Polar Boundary Layer

With the development internationally of the GARP Polar Sub-Programme and increasing Canadian interest in Arctic regions, it has been decided to proceed with a major long-term programme with the following objectives:

> "To reach an understanding of the dynamic and thermodynamic processes in the Arctic Planetary Boundary Layer and the interaction of this layer with the underlying surface",

and

> "To provide advice and consultation related to the impact of this layer on Arctic environmental problems including the prediction of weather and pollutant dispersion."

The first step in the programme will be a comprehensive boundary layer experiment over the ice of Lake Simcoe in February/March, 1977.

Urban Boundary Layer

An existing urban-mesoscale model was borrowed and substantial modifications and improvements have been made.

Results from numerical models for studying the radiative effects of aerosols on thermal structure and pollutant dispersal have been presented at scientific meetings and are being prepared for publication. A slab model approach has been utilized to predict the growth of internal boundary layers. These studies will provide an alternate description of the urban boundary layer and facilitate the examination of several important problem areas. The work on plume modelling has been continued with the long term objective of being able to superimpose point plume sources on the 3-D urban-mesoscale grid point model.

(k) *GATE*

The processing and analysis of GATE data has continued through 1976. By the end of the year the processing of all Canadian GATE data will be essentially finished. The scientific analyses have been concentrated on the radiation data and the boundary layer tethered balloon data. The results to data have shown the data to be of good quality and have revealed some interesting and as yet unexplained features. During the coming year an attempt will be made to couple the different data sets together in order to obtain a more comprehensive picture.

(4) Meteorological Applications Branch

The Meteorological Applications Branch continued with its traditional activities in 1976 of quality control, processing, publishing, and

archiving of weather data and the provision of climatological information and services. Much effort is directed to the application of meteorology to a wide range of Canadian activities. Some highlights of the Branch's activities in 1976 include the establishment of a team to monitor climate, the study of the effects of climatic fluctuations on food production, preparation of streamflow forecasts for the Saint John and Ottawa River basins and the automation of storm rainfall analyses in Canada.

(a) *Climatological Services Division*

This section continued its work of publishing historical and statistical climatological data, and providing climatological information and consultation. Over 12,500 requests for climatological data, information and advice were serviced during the year.

Early in 1976, Climatic Normals, Volume 1-SI Temperature (Celsius) and Volume 2-SI Precipitation (Metric) were distributed. More than 5000 pages of historical data were published in AES periodicals during the year. An extensive archive of climatic data to the end of 1972 is now available on microfiche. Regional offices have now been supplied with duplicate copies of all microfiche for stations in their respective regions. In 1976, more than 350,000 frames of climatic data on microfilm were added to the Division's library.

(b) *Network Standards Division*

The seventh edition of the Manual of Surface Weather Observations (MANOBS) was issued, as were a number of other publications including Supplementary Aviation Weather Observations, the fifth edition of the Manual of Marine Weather Observing, (MANMAR) and Soil Temperature. New reduction to sea level station pressure and altimeter setting tables were recomputed and computer produced for all hourly and synoptic weather reporting stations in Canada.

A start was made at selecting hourly data from principal stations directly from teletype instead of the usual key-punch entry from original documents.

(c) *Hydrometeorology and Marine Applications Division*

The Hydrometeorology and Marine Applications Division is responsible for the application of meteorology to the solution of problems related to both the fresh and salt water environment.

The Hydrometeorology Projects Section became increasingly involved in streamflow forecast studies during 1976. In the Saint John River Basin, a detailed study of the storm rainfall network by objective methods was completed as part of the World Meteorological Organization/World Weather Watch Project. In the Ottawa River Basin, meteorological observations and forecasts were tailored for direct transmission each day during the spring months into a flood forecast model operated by Inland Waters Directorate of DFE. Other projects completed included experimental long range precipitation forecasts, a completed report on the evaporation - sublimation of snow in the eastern Rocky Mountains, and the adaption of Thornthwaite's water budget technique to a day-by-day evaluation in several Canadian basins.

Early in 1975 the Lakes and Marine Applications Section developed the Bulletin of the Monthly and Annual Evaporation from the Great Lakes Bordering on Canada to complement the Great Lakes Basin (Canadian Portion) Precipitation Bulletin. Work on IFYGL projects continued during the year. A paper comparing evaporation estimates from Lake Ontario during IFYGL using several mass transfer formulae

has been prepared. In another project using IFYGL data, approximately 7200 over-lake observations have been paired with simultaneous over-land observations and run through a detailed program to compute ratios, means, extremes and standard deviations of a number of meteorological parameters.

In 1976 the Hydrometeorological Services Section completed the conversion of the Woodbridge radar data collected during the IFYGL to hourly rainfall estimates. Computer plotted intensity-duration-frequency graphs were prepared for recording rain gauge stations with 7 years or more data up to the end of 1975. The analyses for the Storm Rainfall in Canada series has been computerized and processing of major storms from across Canada continued.

(d) *Applications and Consultation Division*

This Division is responsible for developing and providing information on the application of meteorology and climatology to a wide range of Canadian activities and concerns such as forestry and agriculture, industry, recreation and tourism, transportation, land use and arctic exploration, and related problems of climatic change, environmental impacts, food production and energy development.

The Agricultural and Forest Section continued preparation of a comprehensive handbook which will be issued in loose-leaf form with regional sections in 1977. Impact studies were carried out which demonstrate the effects of climatic fluctuations on food and fibre production on both the large and small scales in the major agricultural regions and fringe areas.

The Physical Climatology Section continued field studies of agricultural potential in the north. In the field of recreation climatology extensive reports on the Prairie Provinces, Newfoundland and Labrador, and Prince Albert and Auyuittuq National Parks were issued. Other reports were prepared on current meteorological observations in the James Bay hydro-electric project area (in co-operation with the Quebec Department of Natural Resources) and on land use planning on the national and international scales. Studies of national snow cover and data interpretation continued.

The Industrial Meteorology Section developed and implemented a computer program using real time data to provide weekly and monthly summaries of heating degree days for 96 selected stations across Canada. The Airport Handbook was completed in seven volumes covering all of Canada. Work continued on a program to estimate solar radiation from hourly-reported meteorological parameters and on programs to provide summaries of windchill-cooling rate and humidex of selected Canadian stations.

Work continued in the Arctic Section on preparation of a comprehensive climatology of the Canadian Arctic Islands. A similar study of the Yukon was also in progress. Other aspects of northern climate studied include low temperature fog, year-to-year variations in snow cover and selected weather elements and weather conditions offshore over the ice pack.

Considerable attention was focussed by the Division on problems of climatic change. A Central Services Directorate/Atmospheric Research Directorate Working Group was formed to monitor climate on a global basis.

(e) *Computing Centre Division*

The Computing Centre is responsible for creating and maintaining an archive of climatological data which spans a period of over 125 years. This data file from Canadian stations now contains more than 100 million records, of which over 90% are archived on magnetic tape (800 b.p.i., 9 track). These archives are quality-controlled and current. There are 25 different record types which together encompass all weather elements. The time-scale ranges from hourly to monthly.

Demands for climatological data from users outside the government continued to grow during 1976 with more than 200 received and processed, an increase of 50 percent over 1975.

(5) Ice Branch

The Atmospheric Environment Service conducts programs of ice observing and ice forecasting and provides data and advisory services to support Canada's national and international interests. The complete ice program, which has been developed primarily in support of marine navigation, is now one of the most extensive and complex in the world.

Data gathering is mostly by reconnaissance aircraft, equipped with laser profilometer, infrared scanner, camera array, brute force radar, airborne radiation thermometry, special navigation aids, and special communications facilities. Areas of operations cover the Laurentians, Great Lakes, St. Lawrence River, and coastal areas from Gulf of St. Lawrence across the Arctic to the Beaufort Sea. Data collected include ice extent, type (age), floe sizes, ice topographic features, water openings, snow cover and state of ice deterioration. Satellite data from orbiting weather satellites and LANDSAT imagery are incorporated into forecast and climatological outputs. Fifteen to twenty years of ice data for Canadian waters is now available. Highlights in 1976 include participation by the Branch in the Beaufort Sea Project to support initial offshore drilling, ice climatological studies of various areas, and development of SLAR specifications for an all weather ice reconnaissance system.

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VII VOLCANOLOGY

Compiled by: L.D. Ayres

1. Introduction

When the Volcanology Division of the Geological Association of Canada was established in 1974, it undertook responsibility for compiling the annual report on volcanology. Regrettably no report was available for Volume 28 of the Bulletin. The following report includes projects in progress in 1976 and a partial bibliography for 1975 and 1976.

The report is not complete. Considerable resistance to the compilation was met with from some workers, largely because of the increasing demand from a number of sources for progress reports on current research. Furthermore, many Federal and Provincial geological survey projects, that involve mapping of volcanic terrain, are not included unless additional research on the volcanic rocks is planned or in progress. Further information on these areal projects can be obtained from the individual surveys or from summaries of field work published by some surveys.

2. Archean Greenstone Belts, Superior Province, Canadian Shield

The deformed and metamorphosed, metavolcanic-metasedimentary sequences of the Archean greenstone belts are one of the two major areas of current volcanology research (the other area is the Cordillera). The greenstone belts are the oldest (2.6-2.75 b.y.) widespread unit in the Canadian Shield, and better knowledge of their evolution is a prerequisite for understanding early crustal development. The Superior Province is the natural research focal point because many belts are readily accessible, and mineral deposits are widespread. Current research is concentrated in the Abitibi belt of Ontario and Quebec and the Sturgeon Lake-Lake of the Woods belt in northwestern Ontario, although many projects are in progress in other areas. In addition there are a few general projects spanning many greenstone belts.

(a) General Projects

(i) Geochemical evolution of Archean volcanic piles; A.M. Goodwin, C-L. Chou, and I.E.M. Smith (University of Toronto).

This is a continuing stratigraphic-geochemical study of various volcanic sequences in the Superior Province.

(ii) Regional metallogeny and volcanic stratigraphy of the Superior Province; R.H. Ridler (Geological Survey of Canada).

(iii) Neutron activation analysis for gold in Archean ultramafic and associated volcanic rocks; H.Y. Kuo and H.D.B. Wilson (University of Manitoba).

The main objective is to establish background levels of gold in Archean metavolcanic rocks.

(iv) Oxygen isotope and trace element studies of selected Archean granitic, metavolcanic, metasedimentary, and gneissic rocks; F.J. Longstaffe, R.H. McNutt, and H.P. Schwarcz (McMaster University).

Oxygen isotope ratios have been measured in 300 Archean rocks and associated mineral phases from selected localities in the Abitibi and Wabigoon granite-greenstone and English River gneissic belts. The purpose of the study is to determine the distribution of oxygen isotopes in Archean rocks and minerals, and to evaluate their usefulness as a petrogenetic indicator in such terrains. More detailed aspects of the study involve the comparison of alkali, alkaline-earth and rare earth element abundances in equivalent rock types of varying metamorphic grade to the oxygen isotope results for the same samples.

(b) Abitibi Belt, Ontario-Quebec

(i) General stratigraphic studies

- Rouyn-Noranda area, Quebec. Two research projects by E. Dimroth (Université de Québec, Chicoutimi) and by L. Gélinas (Ecole Polytechnique) and C. Brooks (Université de Montréal).

- Timmins-Kirkland Lake area; D.R. Pyke and L.S. Jensen (Ontario Division of Mines).

- Interrelation of volcanic stratigraphy and mineral deposits, Kirkland Lake area; R.H. Ridler (Geological Survey of Canada).

(ii) Chibougamau volcanism and plutonism; G.O. Allard (University of Georgia, Athens, Georgia, 30602).

A major report summarizing the present state of knowledge in the Chibougamau area has been completed. The Archean volcanic rocks of the Roy Group comprise two mafic to felsic cycles. The lower cycle, the Waconichi Formation, grades upwards from tholeiitic mafic volcanic units to calc-alkaline, porphyritic soda-rhyolite and the exhalite-rich Lac Sauvage iron formation. Some of the rhyolite forms domes. The upper cycle consists of two formations. The lower Gilman Formation comprises tholeiitic pillowed basalt. It is overlain by the Blondeau Formation of calc-alkaline, felsic fragmental rocks. Numerous comagmatic mafic sills have intruded the volcanic sequence. These include the Dore Lake Complex, and the Roberge, Ventures, and Bourbeau Sills.

(iii) Evolution of lava types in the Blake River Group; I.E.M. Smith (University of Toronto).

The volcanic rocks of the Blake River Group display an evolutionary sequence from a basalt-dominant, lower series to an upper series in which andesite is predominant. Although the boundary between these two series is abrupt on a regional scale, it is, in fact, transitional over an interval of one or two kilometers. Rocks near the transition are predominantly lava flows, commonly showing well-developed pillow structure; micro-breccia, spherulitic lava and volcanogenic sediment are a minor component. A suite of samples collected across the transition near the western margin of the Blake River Group include a range of rock types identified petrographically as magnesian tholeiite, iron-rich tholeiite and quartz-bearing fractionated tholeiite; these are accompanied by minor silica-rich, fine-grained and devitrified rocks.

A systematic study of trace element variation in this suite of samples is expected to provide insight into the nature of the compositional changes in the erupted rocks with time. In particular the abundances and relative fractionation of the rare earth elements should provide definite constraints to models which may account for magmatic evolution in the Blake River Group.

(iv) Geology and petrology of tholeiitic lava flows, Lavaflow Mountain, northeastern Ontario; M. Jackson (University of Toronto).

At Lavaflow Mountain near Ramore, high-Fe and high-Mg basalts are interbedded. Massive to coarse-grained flows are more common than pillowed flows and always have well-developed hyaloclastic flow tops indicative of their subaqueous origin. Variolitic pillows are better developed in the high-Fe flows than in the high-Mg flows. Some thick, high-Mg flows have concentrations of glomeroporphyritic plagioclase in the upper parts and this reflects gravitative crystal sorting. The sequence is intruded by numerous hornblende andesite dikes that are probably related to the overlying, calc-alkaline Blake River Group, and by a single mafic dike that may be related to the basaltic flows. Regional metamorphic grade is zeolite facies and primary textures are well-preserved. Petrographic, whole rock chemical, and electron microprobe studies are in progress to determine the relationship between the two types of flows.

(v) Stratigraphy and petrology of Mt. Jamieson Rhyolite, Kamiskotia area, Ontario, D.F. Fisher (University of Toronto).

The Mt. Jamieson Rhyolite occurs near the top of a weakly metamorphosed basalt-andesite-rhyolite pile. It is a sequence of flows with a maximum aggregate thickness of 2 km and a strike length of 8 km. Individual flows are up to 520 m thick and may have been confined within a caldera. Groundmass textures indicate that the flows were originally glassy. During cooling and devitrification, pervasive alkali ion exchange produced compositions of about 7% K_2O and 1% Na_2O. Ovoid autoliths of vesicular devitrified obsidian, 2 to 10 m long, are abundant in 3 of the flows. During emplacement they were highly viscous bodies enclosed by banded or brecciated lava. They formed by retrograde boiling of volatile-rich pockets generated by laminar flow. Spheruloidal nodules (0.8 cm diameter) consisting of many quartz-K-feldspar "orbs" are concentrated toward what was originally the lower side of shear bands in the lava. These bands are about 15 cm thick, 70 cm apart, and form large flow folds throughout the thick core of one flow. Nodules may also occur at the rim of autoliths. In either case, the phenomenon is ascribed to sudden pressure release along shear planes in the viscous lava.

(vi) Investigation of pyroclastic deposits, Noranda area, Quebec; J. Lajoie (Université de Montréal).

(vii) Ultramafic volcanic rocks of Munro Township, Ontario; N. Arndt (Geophysical Laboratory, Washington), A.J. Naldrett (University of Toronto), and D.R. Pyke (Ontario Division of Mines).

(viii) Ultramafic and mafic volcanic rocks and their alteration, Timmins, Ontario, R.E.S. Whitehead and R.S. James (Laurentian University).

(ix) The petrochemistry of the Bachelor Lake volcanic complex, Quebec; G.A. Armbrust and B. McQuade (University of Ottawa).

(x) Geochemistry of well-preserved volcanic units; T.H. Pearce (Queen's University).

Well-preserved Archean rocks exist locally in Archean greenstone belts, such as the Abitibi belt in northern Ontario and Quebec. Carefully selected rocks from these areas whose textures and/or chemistry have been well-preserved are being studied in detail. Fieldwork consists of the selection and sampling of key localities. Digital computer modelling is used to test theories of origin of the rocks and rock series. Data from recent volcanic rocks is being studied for comparative purposes. It is hoped that this latter study will aid interpretation of Archean tectonic environments.

(xi) Geochemistry of the volcanic sequence, Kirkland Lake area, Ontario; L.S. Jensen (Ontario Division of Mines).

Approximately 6000 analyses have been done for Si, Al, Fe, Mg, Ca, Na, K, Ti, Mn, Cu, Ni, Zn, Au, and Cr on rock specimens collected during the course of field mapping in the Kirkland Lake area, Ontario between latitudes 47° 45' and 48° 45' and longitudes 79° 30' and 80° 30' (8300 km^2). The purpose is to distinguish rock types, stratigraphic units and differentiation trends, and to recognize patterns of alteration and areas of anomalous base metal and precious metal concentrations. An additional benefit of the program has been to develop a better means of classifying subvolcanic rocks (Jensen, 1976).

(xii) The distribution of gold, platinum, palladium, and iridium in komatiitic volcanic rocks, Munro Township, Ontario; W.D. MacRae and J.H. Crocket (McMaster University).

The aim of this project is to establish background concentrations of Platinum Group Metals in komatiitic volcanic rocks in Munro Township. In addition other trace elements such as copper, nickel, cobalt and sulphur are being determined. Variations in trace elements in thick pyroxenitic and basaltic komatiitic flows as compared with peridotitic komatiitic flows will be studied. The availability and mobility of gold will also be examined to test the hypothesis that komatiitic volcanic rocks are the source for gold deposits in areas such as Timmins, Kirkland Lake, and Val D'Or-Noranda.

(xiii) Gold distribution in the Kirkland Lake-Larder Lake area, Ontario, with emphasis on Kerr Addison-type ore deposits; L.A. Tihor and J.H. Crocket (McMaster University).

The goal of this investigation is better understanding of the origin and concentration mechanism(s) of gold in quartz-carbonate rock associations. Eighty-nine samples representative of the major rock units of the area have been analyzed by neutron activation analysis

for Au. In addition, major and trace element distribution was studied in 67 samples by optical emission spectroscopy. Preliminary results indicate that most of the rocks of the study area, both Timiskaming and pre-Timiskaming in age, are enriched in Au relative to similar rocks elsewhere. This is especially true of trachytes and the quartz-carbonate units of the Larder Lake "Break" (25.35 and 31.01 parts per billion respectively). Field and geochemical evidence suggest strongly that the quartz-carbonate rocks are mostly carbonatized ultramafic flows, probably of komatiitic affinity.

(xiv) The age of volcanic cycles in well-documented stratigraphic sections in the Abitibi and other greenstone belts and a comparison with the ages of surrounding intrusions; T.E. Krogh (Royal Ontario Museum and University of Toronto).

(c) Sturgeon Lake-Lake of the Woods Belt, Ontario

(i) Volcanic stratigraphy, Savant Lake-Crow Lake area; N.F. Trowell and C.E. Blackburn (Ontario Division of Mines).

A regional study of stratigraphy, structure, and economic geology of the metavolcanic-metasedimentary belts between Savant Lake and Crow Lake.

(ii) Archean volcanic stratigraphy; M.G. Morrice and H.D.B. Wilson (University of Manitoba).

The investigation of the Archean volcanic stratigraphy and geochemistry of the Kenora (Wabigoon) Subprovince continued during 1976. The project, which was initiated in 1972, has involved the stratigraphic mapping of several greenstone belts along corridors. Interpretation between corridors has resulted in the construction of a stratigraphic map for this portion of the Canadian Shield. The stratigraphy has been divided into four major groups or development stages on the basis of field and chemical criteria: lower mafic, middle mafic, middle felsic, and upper diverse. These development stages appear to apply to other shield regions of the world, and the positions of various types of stratabound massive sulphide orebodies can be related to the stages.

(iii) Stratigraphy and development of the Manitou Lake greenstone belt; P.R. Teal (McMaster University).

The Manitou Group, which comprises 4 formations, overlies a thick pillowed and massive basaltic unit that contains minor volcanogenic, graded sandstone and argillite. The basalt represents a large submarine platform upon which the emergent pyroclastic and lava pile of the Manitou Group was erupted. In the Manitou Group, the Cane Lake Formation of coarse pyroclastic rocks passes eastward into the Sunshine Lake Formation of subaerial, porphyritic and vesicular basalt. The Uphill Lake Formation consists of thickly-bedded tuff-breccia and tuff in the southwest, but grades northeastward into more thinly bedded volcanogenic conglomerate and sandstone with rare cross-bedding. Further northeastward, the formation is not exclusively volcanic in origin and displays abundant large-scale (up to 1 m) cross-bedding. The Mosher Bay Formation contains turbidites, conglomerates and argillite. The relationship between the four formations indicates that the pyroclastic pile continued to grow in the southwest, probably developing an alluvial fan upon its flank, whereas in the east a braided stream deposited material from a different source. Finally, the entire area was submerged and was covered by a submarine fan.

(iv) Volcanism in the Washeibamaga Lake area; G. McMaster (McMaster University).

Three periods of volcanic activity can be demonstrated in the Washeibamaga-Thundercloud Lake area. These are a) subaqueous eruption of mafic to felsic, massive, pillowed and porphyritic flows, preserved as a homoclinal volcanic pile; b) late-stage eruption of autobrecciated, porphyritic felsic flows and associated intrusions; and c) explosive volcanism producing pyroclastic laharic deposits on top of the volcanic pile. The spatial and chemical relationships between the various units are being investigated.

(v) Facies analysis of a 6 km thick volcanic sequence, south of Sioux Lookout; R.O. Page and P.M. Clifford (McMaster University).

The lower two-thirds of the pile is pyroclastic rocks and rare flows. The upper one-third exhibits calc-alkaline affinities and spans a range of compositions from basalt to dacite. The extrusive sequence is intruded by a complex of small, commonly composite stocks which are thought to represent sub-volcanic magma chambers which produced the volcanic rocks. Clast size variations, various types of primary structures, and the presence of exotic (rare) lithologies all point to source vents close to the plutonic complex. The distribution of these features has led to the establishment of three volcanic facies related to distance from a source vent: a) cone facies; b) flank facies; and c) distal facies. These facies are not perfectly correlated with distance from the plutonic complex, but this is thought to be a function of initial elongation of vent zones combined with the results of extensive deformation, particularly in the distal facies. Major-element geochemistry of flows and pyroclastic rocks will be used to establish time variations in the eruptive sequence, to test the hypothesis that the plutonic complex and extrusive rocks are genetically related, and to provide basis for comparison with modern, unaltered volcanic rocks. Trace-element geochemistry of refractory elements (especially Zr, Y) will provide additional data for comparison with modern volcanic rocks, and the refractory elements will be tested to ascertain their usefulness in regional correlation.

(vi) Facies analysis of a dacitic, volcaniclastic sequence, northwestern Lake of the Woods, D. Car (University of Manitoba).

The main purpose of this study is facies analysis of volcaniclastic rocks to document vent or near-vent areas, and to determine the nature and environment of volcanism. For this purpose, a 16 km by 3 km vertically dipping, homoclinal, felsic to intermediate sequence in the Western Peninsula region was investigated, with particular emphasis placed on the volcaniclastic units. Heterolithic breccias, oligomictic volcanic conglomerate, tuff, volcanic sandstone, and greywacke are all represented. Several units exhibit graded and non-graded zones. The simultaneous interaction of volcanic and alluvial processes has resulted in a clastic sequence having a high degree of internal complexity. As in most greenstone belts, the volcanic source of the clastic rocks is not exposed. Consequently, location of vents in such areas depends more on facies relations in vent-derived breccia transported away from the vent (distal versus proximal facies) than on identification of actual vents. Criteria used in the study include mode of fragmentation, method of transport, environment of deposition, definition of internal facies relations, and statistical analysis of lithic and mineral components.

(vii) Geochemistry and origin of volcanic rocks, Sturgeon Lake; C-L. Chou and A.M. Goodwin (University of Toronto).

Fourteen metabasalt samples are being analyzed by neutron activation for major and trace elements, including rare earths and potassium. In an earlier study D.G. Beggs had shown that volcanic rocks in this area have bimodal distribution: tholeiitic basalt and dacitic rocks. The K_2O contents of tholeiitic basalts are in the range 0.02-0.2%, comparable to low-K tholeiites of island arcs. The new data will be used to compare Archean volcanic rocks with modern analogs, to study petrogenesis of Archean volcanic rocks and the significance of bimodal magmatism, and to make specific tectonic interpretation of greenstone belts.

(viii) Gold in greenstone assemblages, Kakagi Lake; J.H. Crocket and J. Kwong (McMaster University).

Background gold values in rocks from Kakagi Lake are (in ppb): mafic volcanic rocks, 1.8; felsic volcanic rocks, 1.5; sedimentary rocks, 1.1; intrusive felsic plutons, 1.1-1.2 and mafic-ultramafic intrusions, 0.8. Based on these averages geochemically anomalous gold occurs in the following settings: carbonate rocks in contact with ultramafic intrusions; pyritized shear zones, mainly in felsic volcanic rocks; felsic plutons in association with sodium metasomatism and quartz vein development; and occasionally in quartz veins and felsic (aplitic) dikes. Average gold values in major rock types are apparently not useful guides to potential mineralization. As there is field evidence of preferential occurrence of localized gold enrichment in felsic volcanic rocks from the studies of other workers, we suggest that the metal is more readily released from such rocks, perhaps in response to regional low grade metamorphism. Thus availability, as reflected in mineralogical siting, is probably of more significance than regional background values.

(ix) Gold distribution in the Kakagi Lake volcanic sequence; H.Y. Kuo and H.D.B. Wilson (University of Manitoba).

Gold distribution will be compared with distribution patterns of other trace and major elements in this sequence to seek the controlling factors for gold behaviour in Archean volcanic sequences.

(x) Rare-earth studies, Lake of the Woods; H.Y. Kuo and H.D.B. Wilson (University of Manitoba).

Rare-earth elements and a suite of other trace elements will be determined to establish the distribution of these trace elements in a volcanic sequence typical of many Archean greenstone belts of the Canadian Shield.

(d) Other Ontario Greenstone Belts

(i) Stratigraphy and structure of the Sturgeon River area, northwestern Ontario; W.O. Mackasey (Ontario Division of Mines).

(ii) Shebandowan belt, northwestern Ontario; T.E. Smith, C. Riddle, and A. Turek (University of Windsor).

The geochemistry and petrology of a cross-section of the Archean Crust is being undertaken. The cross-section includes a mafic and felsic volcanic sequence, tonalitic intrusions, K-rich granites, greywackes, and iron formations. It is hoped to reconstruct the complete history of the evolution of this ancient section of the crust

and to evaluate its significance in the early history of the earth and the origin of continents.

(iii) Volcanic stratigraphy of the Confederation Lakes area, northwestern Ontario; P.C. Thurston (Ontario Division of Mines and University of Western Ontario).

(iv) Pyritic and graphitic volcanogenic sediments and their relationship to massive sulphide deposits; L.G. Closs and A.C. Colvine (Ontario Division of Mines).

It has been shown in several mining camps that stratabound base metal, massive sulphide deposits within Early Precambrian volcanic rocks may be located along a specific favourable horizon. This program, begun in 1975, was initiated to investigate the geology and geochemistry of these favourable horizons and to attempt to define features whereby the possibility of, and even the proximity to, base metal concentrations may be predicted. The interpretation of the environment of deposition and the genesis of these deposits, is an integral part of the investigation.

To date, field work has been carried out in the Confederation Lake area, along strike from the South Bay mine and in the Trout Bay area, Mulcahy Township, 30 miles west-southwest of Red Lake. Representative bedrock samples are being analyzed for a full range of major, minor and trace elements.

(v) Stratigraphy and geochemistry of the Favourable Lake volcanic complex, northwestern Ontario; L.D. Ayres (University of Manitoba).

Within a 7.5 km-thick sequence, 5 volcanic cycles have been recognized, each of which represents a separate volcano superimposed on older volcanoes. Most cycles grade upward from a subaqueous tholeiitic basalt to a subaerial, calc-alkaline dacite. Alkalic rocks are locally present in the uppermost cycle. The lowermost cycle represents a subaerial, andesitic to dacitic stratovolcano, the base of which has been destroyed by emplacement of granitic plutons. The four uppermost cycles represent smaller volcanoes superimposed on the northern flank of the stratovolcano, and progressively displaced northward. A major unconformity marks the top of the fourth cycle. Studies are in progress on the entire complex and on specific aspects as outlined below.

(vi) Fumarolic alteration of basaltic flows, Favourable Lake, northwestern Ontario; L.D. Ayres (University of Manitoba).

Basaltic flows associated with sulphide-facies ferruginous chert in the Favourable Lake volcanic complex and elsewhere are strongly altered. The alteration is commonly zoned with an outer epidote + diopside zone, a central diopside + epidote + garnet + amphibole + pyrrhotite zone and an inner quartz + epidote + diopside + amphibole zone. Petrographic and chemical studies are in progress.

(vii) A dacitic to andesitic, caldera-filling sequence, Favourable Lake, northwestern Ontario; P.S. Buck (University of Manitoba).

Felsic volcanic rocks at the top of Cycle 2 of the Favourable Lake volcanic complex occupy a caldera. This caldera has a diameter of 5.6 km and is filled to a depth of 1.4 km by flows and vent facies, pyroclastic rocks. The caldera formed by collapse during the final stages of growth of a subaqueous to possibly subaerial basaltic shield volcano on the north flank of the main stratovolcano. Contemporaneous with collapse, subaerial, dominantly explosive, andesitic to dacitic

eruptions occurred along the margins of the caldera, and the products of these eruptions partly filled the caldera. Following volcanism, parts of the caldera sequence were eroded and the detritus was deposited in a lake confined by the caldera. Alteration during the waning stages of volcanism resulted in extensive migration of CaO, Na_2O, and K_2O.

(viii) Tholeiitic sheeted sill complex, Favourable Lake volcanic complex, northwestern Ontario; M. Raudsepp (University of Manitoba).

This complex is only 300 m thick but contains five distinct pyroxenite to gabbro cumulate sequences. It occurs in the central part of the volcanic complex and may represent a high level magma chamber.

(ix) Sedimentology of formation K, Favourable Lake volcanic complex, northwestern Ontario; W. Gordanier (University of Manitoba).

The formation is 1 km thick and comprises a lower conglomerate member and an upper greywacke member. The conglomerate represents an alluvial fan derived from a mixed volcanic-plutonic provenance. In places the matrix of the conglomerate is strongly altered with epidote and diopside replacing the original clastic constituents. The greywacke is a quartz-rich, turbidite association and indicates submergence of the alluvial fan. The provenance is also mixed volcanic-plutonic, but the greywacke, in large part, appears to represent erosion of concomitant felsic pyroclastic deposits on the subaerial part of the volcano. The formation records volcanic events that are not preserved elsewhere in the volcano.

(e) Manitoba Greenstone Belts

(i) Stratigraphy and structure of the Bird River greenstone belt; D.L. Trueman (University of Manitoba).

(ii) Geochemistry of granitic and volcanic rocks of the Oxford Lake-Knee Lake-God's Lake region; J.J. Hubregtse, H.P. Gilbert, and F.J. Elbers (Manitoba Mineral Resources Division).

Detailed geochemical and petrological investigations are in progress to unravel the evolution of the greenstone belts and surrounding granite-gneiss terrains.

(iii) Morphology and geochemistry of basalt flows, Utik Lake; R. Hargreaves (University of Manitoba).

A 900 m-thick sequence of aphyric to microporphyritic, pillowed, massive, and brecciated metabasalt flows is being examined. Many of the pillows have irregular shapes and some appear to be the submarine equivalent of pahoehoe toes. Primary textures including quench plagioclase are well preserved. Massive and pillowed flow units, ranging in thickness from 3-35 m, are intimately interlayered, and a major focus of the study is determining what constitutes a single flow in such a sequence. Geochemical work is in progress to determine the internal variation within flows, the effect of sea water alteration in the pillowed and brecciated portions and the interflow variation.

(iv) Fox River area; R.F.J. Scoates (Manitoba Mineral Resources Division).

Pillowed and massive, mafic volcanic rocks of Paleohelikian (?) age are interlayered with sedimentary rocks and differentiated

intrusions and have been affected by low-grade metamorphism ranging from prehenite-pumpellyite to middle greenschist facies. Primary structures and textures are well preserved. Composite massive flows occur in the lower parts of the volcanic cycles. These flows have a lower zone of cumulus minerals (olivine ± clinopyroxene) in a groundmass of altered glass and skeletal crystals (clinopyroxene ± plagioclase), and an upper polygonal, columnar jointed zone of altered glass, some unsettled crystals and skeletal crystals (olivine ± clinopyroxene ± plagioclase). The flow tops are brecciated and vesicular, and contain finely dispersed graphite. Composite flows range in composition from ultramafic to mafic and individual flows vary in composition from base to top. The flows probably originated as extrusions of crystal-charged lava and subsequent settling of the suspended crystal phase to form a lower zone of cumulus minerals. During this process, the fluid phase quenched giving rise to an upper zone of skeletal crystals in a glassy groundmass.

3. Archean Greenstone Belts, Slave Province, N.W.T., Canadian Shield

(a) Geochemistry of volcanic rocks near Agricola Lake; E.M. Cameron (Geological Survey of Canada).

About 500 samples have been analyzed for major and trace elements.

(b) Strontium isotopic, whole-rock, trace and rare-earth chemistry of volcanic and granitic rocks in the Indin Lake-Hackett River-Back River areas; R.A. Frith (Geological Survey of Canada).

(c) Petrology of part of the Hackett River greenstone belt; M.P.D. Bryan and C.M. Scarfe (University of Alberta).

(d) Back River volcanic complex; M.B. Lambert (Geological Survey of Canada).

A large felsic volcanic complex, centred on 65 degrees north latitude with 108 degrees east longitude about 480 km northeast of Yellowknife, is being mapped to determine: (1) the stratigraphy and internal structure; (2) relationship of the volcanic pile to the surrounding granitic and sedimentary rocks; (3) criteria for identification and interpretation of metamorphosed felsic volcanics in the Slave Province; and (4) the mode and environment of volcanic eruption.

The complex comprises felsic to intermediate volcanic rocks that lie conformably (in the northern part of the complex) on greywacke and shale typical of the Yellowknife Supergroup; the sediments surround the volcanic complex. Iron-formation, associated with black carbonaceous shale and siltstone, locally lies near the contact between sedimentary and volcanic successions. Rhyolite and dacite tuffs, breccias and massive units represent domes and associated flows and ash flows. Andesite occurs as pillowed flows, breccias and tuffs. Basaltic rocks, almost invariably in the form of pillowed flows, make up a minor proportion of the complex. Plutons of granodiorite and adamellite and swarms of gabbro dykes intruded both sedimentary and volcanic rocks.

Volcanism began with effusion of mafic to intermediate flows in a subaqueous environment. The volcanic pile emerged above sea level where felsic domes, flows and ash flows dominated the succession.

4. Archean Greenstone Belts, Churchill Province, Canadian Shield

(a)Rankin-Ennadai Belt, N.W.T.

Most research is being concentrated in this belt, which is the largest of the Archean greenstone belts within the Proterozoic Churchill Province.

(i) Volcanic study in the Ennadai belt; R.H. Ridler (Geological Survey of Canada).

(ii) Stratigraphy and structure, Turquetil Lake area; K. Barrett (University of Manitoba and Department of Indian and Northern Affairs).

In this area, in the northeastern part of the belt, an 11 km-thick sequence is being examined. Two mafic to felsic cycles have been identified. The lowermost portion of each cycle comprises pillowed basaltic flows and this is capped by thick andesitic pyroclastic sequences. The andesite grades laterally into major felsic volcanic centres.

(iii) Copper-zinc showings and their relationships to volcanic stratigraphy, South Heninga Lake; S. Leggett (University of Manitoba and Department of Indian and Northern Affairs).

In this area, which is also in the northeastern part of the belt, a sequence of mafic flows and subvolcanic intrusions is overlain by intermediate to felsic flows and fragmental rocks. Copper-zinc mineralization occurs in a cherty tuffaceous unit within the intermediate fragmental sequence.

(b) Other Greenstone Belts

(i) Northern Lights Group (volcanic), Deschambault Lake, Saskatchewan; R. Macdonald and G.A. Posehn (Saskatchewan Geological Survey).

(ii) Volcanic rocks of the Prince Albert Group, Melville Peninsula, N.W.T.; M. Schau (Geological Survey of Canada).

5. Proterozoic Volcanism in the Churchill Province, Canadian Shield

(a) Early Proterozoic (Aphebian) Greenstone Belts.

(i) Amisk Group volcanism and sedimentation, File Lake area, Manitoba; A.H. Bailes (Manitoba Mineral Resources Division).

Volcanic rocks in this area, which is at the east end of the Flin Flon greenstone belt, are dominantly tholeiitic in composition. Basaltic and andesitic varieties have low TiO_2 and K_2O contents and chemically resemble modern low-K island arc tholeiites. The sedimentology, petrology and stratigraphy of Amisk Group sedimentary rocks indicates that they are a proximal turbidite sequence derived from and composed of felsic to intermediate volcanic detritus.

(ii) Volcanic stratigraphy near the mines of the Flin Flon-Snow Lake area, Manitoba; E.H.B. Mwanang'onze (University of Manitoba).

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

At Missi Island in the western part of the Flin Flon belt, tholeiitic subaqueous basalt of the Amisk Group is intruded by two subvolcanic, plutonic suites. The older suite, a series of relatively

thin, porphyritic sills and dikes has associated hydrothermal alteration and chalcopyrite-pyrite mineralization. The sills and dikes are concentrated in several concordant lenses that are 100% intrusive rock; sills and dikes are relatively sparse away from these lenses. Each lens appears to have been the locus of repeated intrusion, with each intrusive pulse gradually expanding the size of the lens. The younger suite comprises ovoid to irregular trondhjemite stocks.

(iv) Volcanic stratigraphy and mineralization in the Amisk Group, west of Amisk Lake, Saskatchewan; J.S. Fox (Saskatchewan Research Council).

(v) Lynn Lake greenstone belt, Manitoba; H. Zwanzig, H.P. Gilbert, and E.C. Syme (Manitoba Mineral Resources Division).

A re-investigation of the Lynn Lake greenstone belt was initiated in 1976. The project will emphasize volcanic stratigraphy, the relationship between volcanism on the north and sedimentation on the south, and the position of mineral deposits in the stratigraphic succession.

(b) Middle Proterozoic Volcanism

(i) Volcanism in the Dubawnt Group, N.W.T.; D.H. Blake (Geological Survey of Canada and Bureau of Mineral Resources, Australia).

The study is aimed at determining the distribution of the various volcanic rocks, the types of volcanicity represented, their stratigraphic relationships, tectonic setting, and petrological affinities, and their genetic relationship, if any, to spatially associated uranium mineralization. The volcanic rocks are isotopically dated at about 1750 m.y. and have not been affected by regional metamorphism. They comprise subaerial flows and pyroclastic rocks, volcaniclastic and tuffaceous sedimentary rocks, mixtures of volcanic and sedimentary rocks interpreted as hyaloclastites, vent breccias, and various high level intrusions. The extrusive and associated sedimentary rocks (Christopher Island Formation) overlie and interfinger with gently dipping, highly feldspathic, non-volcanic probably fluvial clastic rocks (Kazan and South Channel Formations), but locally unconformably, overlie crystalline basement. They are overlain by flat-lying, mainly quartzose sandstone (Thelon Formation) which is probably at least partly marine. Several small eruptive centres, the sites of both lava extrusion and explosive activity, have been identified; most of these were located on alluvial fans and plains adjacent to basement highlands and close to active major faults. The lavas are mainly potassium-rich and are provisionally classified as trachytes, although some rhyolite is also present. The trachytes contain biotite and augite phenocrysts and have alkali feldspar as the dominant groundmass phase. Propylitic (hydrothermal) alteration, with the development of secondary carbonate and chlorite is widespread.

6. Proterozoic Volcanism, Southern Province, Canadian Shield

Huronian volcanism, Thessalon area, Ontario; G. Bennett (Ontario Division of Mines).

7. Proterozoic Volcanism of the Coronation Geosyncline, N.W.T.

(a) Volcanism in the Athapuscow Aulacogen, Great Slave Lake; P.F. Hoffman (Geological Survey of Canada).

The Athapuscow Aulacogen is an epi-cratonic rift zone of Aphebian age related to the Coronation Geosyncline. The aulacogen was mapped at 1:50,000 scale in 1976 in order to elucidate its structural and magmatic development. Volcanic rocks occur in nearly every formation and more than 40 discrete volcanic centres have been located. The most widespread volcanism occurred during deposition of the Sosan and Kahochella Groups, when volcanic centres, now marked by basaltic breccia pipes, submarine pyroclastic cones, and multicycle complexes of reworked tuffs and flows, developed along old fault lines. A single line of felsic centres, marked by large rhyolitic domes and intervening welded tuffs, developed simultaneously with basaltic volcanism elsewhere in the aulacogen. Intimately associated flows of mafic and felsic composition occur at the base of the Wilson Island Group, of probably early Aphebian age. This suggests that there may have been a stage of rifting in the early Aphebian that predates the main development of the aulacogen in the late Aphebian.

(b) Volcanologic evidence for the origin of the East Arm, Great Slave Lake; S.P. Goff and C.M. Scarfe (University of Alberta).

(c) Volcanism and plutonism in the Great Bear batholith; P.F. Hoffman (Geological Survey of Canada).

The Great Bear batholith is an epi-eugeosynclinal volcano-plutonic rift zone of late Aphebian age related to the Coronation Geosyncline. The rift is bounded on the east by the Wopmay Fault and is at least 450 km in length and 125 km in width. It is filled by enormous thicknesses of continental dacitic to rhyolitic welded tuffs, and lesser amounts of basaltic, andesitic and rhyolitic flows. The volcanic piles are broadly folded and intruded by large epizonal plutons that range from synvolcanic, sill-like monzonites and adamellites, to post-volcanic granites. The rift zone is interpreted as a continent-margin, intra-arc depression and, as such, confirms the Cordilleran affinities of the Coronation Geosyncline.

8. Volcanism in the Canadian Appalachians

Only two projects, both from Newfoundland, have been reported for this region. Other volcanologic research is known to be either in progress or recently completed in this region, but information on specific projects is not available.

(a) Petrochemistry, stratigraphy, and structure of the Late Precambrian Love Cove Group, Newfoundland; V.S. Papezik, E. Hussey, and A. DalBello (Memorial University).

The Love Cove Group (Jennes, G.S.C. Memoir 327, 1963) consists of felsic flows and pyroclastic rocks, with lesser amounts of mafic rocks and associated sediments, all of Hadrynian age. In contrast to rocks of similar age on the Avalon Peninsula, the Love Cove Group is intensely deformed and shows prominent schistosity and mineral assemblages of the greenschist facies. The rocks are of interest because of their proximity to the western margin of the Avalon Zone, a tectonic position comparable to that of the Carolina Slate Belt. The study is designed to provide basic chemical and petrological data on the volcanic rocks included in the Love Cove Group of Jenness, as well as additional data on structure and stratigraphy of the group and its possible correlation with other volcanic rocks of the Avalon zone. Parts of the study will be used for two M.Sc. thesis by Hussey and DalBello.

(b) Harbour Main volcanic rocks, Avondale area, Newfoundland; G. Ford and C.J. Hughes (Memorial University).

9. Volcanism in the Canadian Cordillera

Volcanism in the Canadian Cordillera ranges in age from Late Precambrian to Recent but most of the research emphasis is on Mesozoic and Cenozoic volcanism, including thermal springs. The Cordillera and the Superior Province of the Canadian Shield are the two major focal points of volcanological research.

(a) General Projects

(i) Oxygen isotope geochemistry of volcanic rocks in western Canada, including investigation of alteration of terrestrial volcanic material; K. Muehlenbachs (University of Alberta).

(ii) Rb-Sr isochrons for various Paleozoic to Early Cenozoic volcanic and related plutonic units; R.L. Armstrong (University of British Columbia).

(b) Mesozoic Volcanism

(i) Upper Triassic Takla Group, McConnell Creek area, north-central British Columbia; J.W.H. Monger (Geological Survey of Canada).

This is the initial phase of an on-going project on stratigraphy of Upper Triassic volcanogenic rocks in north-central and northwestern British Columbia. These rocks are of considerable economic importance as they contain or are associated with numerous copper showings. The little metamorphosed Takla Group, west of Pinchi Fault, comprises three formations that are differing facies of a marine to locally non-marine, evolving volcano-sedimentary assemblage. The Dewar Formation, up to 1500 m of dark-grey to brown volcanic sandstone, tuff and argillite, both underlies and is the distal, basinward, equivalent of volcanic rocks of the Savage Mountain Formation. The latter comprises up to 2000 m of dark grey-green, locally red, pillowed basalt, massive basalt, breccia and tuff, with, in places, thin, subaerial basalt flows at the top. The basalts are porphyritic, with abundant augite, serpentine pseudomorphs after olivine, and plagioclase phenocrysts and have alkaline affinities. Both formations are overlain by the Moosevale Formation, which consists of up to 1800 m of variegated red and green or reddish-grey marine and non-marine volcaniclastic rocks. Some clasts are similar to those of the Savage Mountain Formation and others are intermediate, alkaline, feldspar porphyry. East of Pinchi Fault the rocks are metamorphosed, mainly in the greenschist facies, but probably are largely correlative with the Savage Mountain Formation. Fossils are Upper Karnian and lowermost Norian (Upper Triassic) and the whole succession thus represents deposition in a relatively short time interval.

(ii) Upper Triassic Nicola Group between Merritt and Princeton, south-central British Columbia; V.A. Preto (British Columbia Ministry of Mines and Petroleum Resources).

Nicola rocks within the area mapped can be divided into three northerly-trending belts which are separated by regional high-angle faults. These are recognized as old structures which controlled Nicola magmatism and sedimentation and which were re-activated in Early Tertiary time to produce basins filled with continental volcanic and sedimentary rocks. Nicola volcanic rocks are mostly basaltic and include products of both alkalic and calc-alkalic magmatism, with the

alkalic group being far the most common. Analcite phenocrysts occur in many trachybasalt flows. Copper mineralization is widespread in the central belt of Nicola volcanic rocks and the most important deposits are of the porphyry type and closely associated with high-level Nicola intrusions. Large copper and gold-skarn deposits occur in the predominantly sedimentary basins which flank the central volcanic zone to the east and west.

(iii) The Iron Mask batholith and associated Upper Triassic, Nicola Group volcanic rocks, Kamloops, British Columbia; K.E. Northcote (British Columbia Ministry of Mines and Petroleum Resources).

Observed geologic features of Iron Mask batholitic and Nicola volcanic rocks are consistent with a single but pulsating comagmatic and partly coeval volcanic-plutonic system with the batholith being emplaced in a subvolcanic to near-surface volcanic environment.

(iv) Late Triassic Nicola Group volcanic rocks, Promontory Hills, south-central British Columbia; W.J. McMillan (British Columbia Ministry of Mines and Petroleum Resources).

Mapping at 1:6,000 was begun during 1976, west of Craigmont Mine in order to outline the structure and stratigraphy of the Nicola Group. An attempt is being made to trace the stratigraphy eastward toward Craigmont Mine, but this is being hampered by tight folding, faulting, and by Cretaceous volcanic rocks near the Mine.

(v) Late Triassic Nicola Group volcanic rocks, north of Merritt, British Columbia; W.J. McMillan (British Columbia Ministry of Mines and Petroleum Resources).

(vi) Jurassic stratigraphy and history and north-central British Columbia; H.W. Tipper and T.A. Richards (Geological Survey of Canada).

The Hazelton Group in north-central British Columbia is a Lower to Middle Jurassic calc-alkaline volcanic island arc assemblage. It is divided into three formations, the Telkwa, Nilkitkwa and Smithers Formations. It overlies with small angular discordance the alkaline basalts of the Takla Group and is overlain conformably by the deltaic successor basin assemblages of the Bowser Lake Group. The Telkwa Formation of Sinemurian age comprises more than 1000 m of rhyolitic to basaltic volcanic rocks, of which andesite and dacite predominate. A central subaqueous volcanic region is flanked to east and west by large areas (20,000 km^2) of variegated reddish, subaerial flows, epiclastic, and volcaniclastic rocks. Above the Telkwa Formation, the Nilkitkwa Formation of Pleinsbachian to Toarcian age is a thick (1500 m) assemblage of shale, siltstone, greywacke and limestone interbedded with as much as 50% felsic air-fall tuff and tuff-breccia deposited in a marine basin. Lenses of basaltic aquagene breccia are interspersed throughout the section. One of these, the Ankwell Formation, is more than 1500 m thick, and for part of its history was an island. Coeval volcanism in the west was characterized by extensive deposition of brick-red, air-fall lapilli-tuff and fine breccia. The final stage of volcanism in the Hazelton Group is represented by air-fall tuff contemporaneous with marine sedimentation of the Toarcian to Bajocian Smithers Formation. This phase represents the last significant submarine island arc volcanism in the Canadian Cordillera.

(vii) Bonanza Formation volcanic rocks on Carnation Creek, Vancouver Island; G.E.P. Eastwood (British Columbia Ministry of Mines and Petroleum Resources).

This study is part of a multidisciplinary investigation of the effects of logging on a typical watershed. Massive to locally bedded rhyolite crystal tuff predominates. A partial analysis of the tuff gave 71.0% SiO_2, 0.9% CaO, 4.3% Na_2O, and 3.7% K_2O. Amygdaloidal flows and less silicic rocks are locally intercalated with the rhyolite tuff. The formation is partly altered to epidote, chlorite, sericite, and carbonate, and is intruded by three small diorite and quartz diorite stocks and by several granitic dikes.

(viii) Petrogenesis of the Cretaceous, analcime-bearing and associated volcanic rocks of the Crowsnest Pass area, Alberta; L.J. Ferguson, A.D. Edgar, C. Herzberg, and R. Gill (University of Western Ontario).

(c) Cenozoic Volcanism

(i) Regional study of Rb, Sr, and Sr isotopes in Late Cenozoic volcanic rocks; R.L. Armstrong (University of British Columbia).

(ii) K-Ar investigation of episodic and time-transgressive volcanic patterns; R.L. Armstrong (University of British Columbia).

(iii) Rare earth element content of selected Cenozoic volcanic complexes; R. Arculus and J.G. Souther (Geological Survey of Canada). Mt. Edziza is the first centre sampled.

(iv) Cenozoic geology of the western Cordillera; J.G. Souther (Geological Survey of Canada).

A compilation of all available data on the Cenozoic of British Columbia, Yukon, and adjacent off-shore areas is being made at a scale of 1:500,000. The maps will show the distribution, age and composition of Cenozoic volcanic and plutonic rocks as well as sedimentary basins and structures that formed or are known to have been active during the last 50 million years. An attempt is being made to include as much geophysical data as possible. The aim of the project is to provide a better understanding of the tectonic environment that fostered the changing pattern of Cenozoic volcanism in the western Cordillera.

(v) Uranium mineralization associated with Cenozoic volcanic rocks in British Columbia; P.A. Christopher (British Columbia Ministry of Mines and Petroleum Resources).

As part of a study of the environment of deposition of uranium in southern British Columbia, interest has been concentrated on Cenozoic volcanic rocks and Cenozoic basins with potential for basal type uranium deposits. In the Okanagan two environments are presently being studied: a) unconsolidated sediments capped by Pliocene (K-Ar age 4.7 m.y.) and Miocene (?) plateau basalts, and b) non-marine Eocene basins (e.g. White Lake Basin) with mainly phonolite, trachyte, and andesite flows.

(vi) Tertiary volcanism and graben structures in south-central British Columbia; B.N. Church (British Columbia Ministry of Mines and Petroleum Resources).

In the Hat Creek area a large zone of Tertiary volcanic and sedimentary rocks has subsided along a series of north-trending tension faults, forming a prominent graben. The main sedimentary units, the Coldwater Formation, Hat Creek Coal Formation, and Medicine Creek Formation, rest partly on andesite flows (88.3 m.y.) assigned previously to the Spences Bridge Group. These sedimentary units, in turn, are overlain by the Kamloops Group rhyolite flows (49.9 m.y.)

and andesite and dacite flows and lahar deposits (43.6 m.y.). The succession is capped locally by olivine basalt dated at 13.8 m.y. A pattern of northerly oriented grabens extends eastward across the interior region of British Columbia from Hat Creek through the Penticton area to Greenwood. Moving easterly in this system the frequency of alkaline volcanic rocks increases. The coincidence of high radioactivity and the alkaline volcanic suite is presently being investigated.

(vii) Granite Creek area, British Columbia; W.J. McMillan (British Columbia Ministry of Mines and Petroleum Resources).

Moderately-dipping volcanic rocks are intruded by a large Tertiary (?) granodiorite pluton, and both units contain copper and gold mineralization. Mapping and K-Ar dating are being done to determine the age of mineralization and whether mineralization in the volcanic and plutonic rocks are related.

(viii) Eocene Metchosin volcanic rocks and Sooke intrusions, southern Vancouver Island; J.E. Muller and E.J. Schwartz (Geological Survey of Canada).

Geological, geochemical, and paleomagnetic work is in progress at the south end of Vancouver Island. Here a sequence of tholeiitic pillowed flows with minor intercalated volcaniclastic rocks is overlain by amygdaloidal basalt flows. The basalt sequence overlies olivine gabbro and is intruded by diabase dikes and small tonalitic to trondhjemitic, commonly agmatitic plutons. The sequence appears to represent Eocene ocean floor and basement.

(ix) Quarternary calc-alkaline volcanism, Gardibaldi Lake, southwestern British Columbia; N. Green (University of British Columbia).

Detailed mapping has established stratigraphic sequences within the andesitic volcanoes of the Garibaldi Lake area, and generalized successions within the larger strato-volcanoes of Mount Garibaldi and Columnar Peak. Limited K-Ar dating has established a generalized eruptive history for the area. Measurements of major and trace element geochemistry of the Garibaldi Lake suites, coupled with micro-probe analysis of their constituent minerals, has allowed constraints to be placed on possible petrogenetic models.

(x) Geochemistry of Quarternary volcanism, Garibaldi area, southwestern British Columbia; N. Green, B. Watters, and B. Anderson (University of British Columbia).

Major and trace element data for volcanic suites of the Paul Ridge, Mount Garibaldi, Meager Mountain, Mount Cayley and Bridge River regions, plus a few K-Ar dates, and Sr^{87}/Sr^{86} measurements for representative lavas have been used to identify regional compositional variations. There is a possibility that more than one mechanism of origin has been responsible for the generation of the andesitic lavas.

(xi) North flank of Rainbow Range shield volcano and nearby Anahim Peak, southwestern British Columbia; M.L. Bevier (University of British Columbia).

A succession of peralkaline trachyte, trachybasalt, and capping alkali olivine basalt is being investigated by chemical and isotopic methods.

(xii) Rb-Sr investigation of ultramafic nodules from volcanic rocks of Boss Mountain and Jacques Lake, British Columbia; B. Maxwell (University of British Columbia).

(xiii) Mt. Edziza volcanic complex, northern British Columbia; J.G. Souther (Geological Survey of Canada).

Field and laboratory work have been completed. The Edziza complex is now known to include two circular, cauldron subsidence-ring dike complexes, each associated with irregular intrusions of syenite. These are believed to be the principal vents from which the Armadillo (5 to 6 m.y.) and Spectrum (2 to 3 m.y.) ash flows were erupted.

(xiv) Petrology of the Heart Peaks volcanic centre, northern British Columbia; J.J. Casey and C.M. Scarfe (University of Alberta).

(xv) Alkaline volcanism in the Level Mountains volcanic centre, northern British Columbia; T.S. Hamilton, C.M. Scarfe, and H. Baadsgaard (University of Alberta).

(d) Geothermal Studies

(i) Geothermal areas, Cordilleran Yukon, Northwest Territories, and adjacent British Columbia; J.T. Crandell and T.L. Sadlier-Brown (Geological Survey of Canada).

Forty-two thermal and mineral springs and two areas of Tertiary and Quarternary volcanism have been examined. Data collected includes discharge rates, temperature, nature of precipitates, water chemistry, and local geologic setting. Electrical self-potential traverses were run across 13 of the thermal areas.

(ii) Meager Creek volcanic complex, southwestern British Columbia; P.B. Read (Geological Survey of Canada).

This is a detailed geological study to provide data for an assessment of geothermal potential. Three major volcanic assemblages of the Garibaldi Group form the Meager Creek Volcanic Complex. The oldest assemblage consists of a basal volcanic breccia, and overlying dacite, aphanitic basalt, and a highly altered felsic tuff and breccia unit. Andesite flows and breccias comprise the middle assemblage which is at least as old as 4.2 m.y. and as young as 2.1 m.y. Dacite flows, breccias and intrusions dominate the upper sequence which locally overlies till. It ranges in age from interglacial to as young as postglacial for the Bridge River Ash (2400 $\pm$ 140 B.P.) and a still younger flow which are part of the upper sequence. The volcanic complex overlies a basement composed of Mesozoic plutonic and metamorphic rocks which are unconformably overlain by low-grade metavolcanic rocks all of which are intruded by quartz monzonite stocks of presumed Miocene age. The hotsprings issue from basement.

(iii) Geochemistry of thermal waters, Mt. Meager hotsprings, southwestern British Columbia; L.T. Hammerstrom and T.H. Brown (University of British Columbia).

The Mt. Meager hotsprings, 160 km north of Vancouver, is a potential geothermal energy source. This study will use the results of chemical analyses of thermal spring waters and surficial fresh waters in the area to construct thermodynamic models of the possible chemical conditions in the thermal reservoir. The models will be used to determine if observed alteration products found in drill cores from the area are the result of the thermal waters reacting with the host rock. In addition, an estimate of the maximum thermal reservoir

temperature will be attempted using existing or new geothermometer principles.

10. Sea-Floor Volcanism

(a) Leg 37, Deep Sea Drilling Project

Samples collected from the five holes drilled into the basalt layer of the sea floor on the west side of the Mid-Atlantic Ridge near 37°N are being examined at a number of Canadian institutions including the Geological Survey of Canada, Atlantic Geoscience Centre, University of Alberta, University of Calgary, Dalhousie University, McGill University, McMaster University, Université du Québec à Montréal, Queen's University, Saint Mary's University, University of Toronto, and University of Western Ontario. Preliminary results were reported at the 1976 meeting of the Geological Association of Canada in Edmonton, and are being prepared for publication.

(b) Secondary minerals in some basalts from DSDP Legs 3, 11, 26, and 27; C.M. Scarfe (University of Alberta).

(c) Oxygen isotope geochemistry of ocean-floor basalt; K. Muehlenbachs (University of Alberta).

Basalts from the oceanic crust (recovered by DSDP and IPOD) are being analyzed in order to determine the extent and temperature at which the basalts have been altered by seawater. The aim of this project is to evaluate the extent of seawater/crust interaction.

(d) Petrology of basalt dredged from the Mid-Labrador Sea; P. Newman and D.B. Clarke (Dalhousie University).

(e) Seamounts of the northeastern Pacific Ocean; R.L. Chase (University of British Columbia).

A 3-day survey was made of Oshawa Seamount (52°15.6'N, 134°03.2'W) aboard CFAV Endeavour in July 1976. The seamount lies on Oshawa rise, a linear swell trending northwesterly between western Queen Charlotte Sound and Bowie Seamount. Oshawa Seamount is a symmetrical conical structure with a summit crater. Depth to the summit is 898 m. Subalkaline basalt dredged from the summit yielded whole-rock K-Ar ages of 4.9 ± 0.4 and 5.8 ± 0.6 million years. A K-Ar whole-rock age from the interior of a hawaiite pillow from J. Tuzo Wilson Knolls, at the southeastern end of Oshawa rise, was 0-54,000 years.

11. Other Projects

Included in this category are three projects that span two or more tectonic provinces.

(a) Plateau basalts; W.R.A. Baragar (Geological Survey of Canada).

The major plateau basalt provinces of the Canadian Shield (Keweenawan, Coppermine River, Seal Lake, and Natkusiak), now mapped and systematically sampled, provide a basis for a general appraisal of plateau basalts and their tectonic significance. The provinces differ significantly in composition and distribution of compositions: 1) the Seal Lake province comprises olivine basalt transitional between tholeiitic and alkali basalt and of very limited compositional range; 2) Keweenawan basalt is olivine tholeiite but the province ranges in composition from basalt to rhyolite, a feature generally attributed to crustal contamination; 3) the Coppermine River province consists of tholeiites which increase markedly in iron content with decreasing age of eruption, and 4) the Natkusiak basalts are

a fairly uniform low-olivine tholeiite. Despite these differences the plateau basalts are in common richer in K, Ti, and incompatible trace elements than are basalts of the greenstone belts, the other major volcanic association of the Canadian Shield. In this respect they bear the same relationship to greenstone basalts as do oceanic island volcanic rocks to ocean-ridge basalts. Whatever the origin of oceanic islands, the plateau basalts may well be their counterparts on the continents. To test this comparison further, rare earth studies on the plateau basalts are the next logical step.

(b) Volcanogenic mineral deposits and sedimentary rocks: G.A. Gross and C.R. McLeod (Geological Survey of Canada).

The study of iron-formation and related sediments of volcanogenic affinity initiated in the 1940's is being continued in the current program on iron and manganese resources. A file on geochemical data for major and minor elements in the iron-formations is being developed and current research emphasizes the use of these data in identifying the broad range of environmental conditions for the deposition of iron and manganese. Current study of metalliferous sediments and manganese nodules along oceanic rift systems and in deep ocean basins provide exceptional insight, from contemporary volcanic processes, into the formation of mineral occurrences throughout geological time.

(c) Volcanism and plutonism associated with Middle Proterozoic rifting in North America; R.F. Emslie (Geological Survey of Canada).

Anorogenic Elsonian magmatic activity in Labrador about 1400 to 1500 m.y. produced a suite of anorthosite massifs and associated adamellites and granites (some with rapakivi textures). Similar rocks as well as rhyolitic volcanic rocks and subvolcanic granitic intrusions (some with rapakivi textures) were emplaced in a broad belt from Wisconsin to Arizona at about the same time. The distribution of anorthosite massifs and associated quartz mangerites of the Grenville Province lies along, and subparallel to, this trend but the dates of intrusion of these rocks are subject to some controversy. Shortly after 1400 m.y., sedimentary basins began to form in Labrador (Seal Lake Group), in the mid-continental United States and adjacent Ontario (Puckwunge Formation, Sibley Group) and on the northeastern extension of this trend in southern Greenland (Eriksfjord Formation). All of these basins began to fill with continental sediments and not long thereafter became the sites of basaltic (tholeiitic to mildly alkalic) intrusion and extrusion. This apparent consistent sequence of events, overlapping in time and occurring in widely separated localities is believed to be the result of developing activity in the mantle along a broad linear zone beneath the continent. In Labrador, uplift of 10 to 15 km accompanied and followed intrusion of the anorthosite-adamellite suite and probably resulted in crustal attenuation and basin development culminating in production of the Seal Lake rift zone. A similar sequence of events is inferred for the mid-continental United States. The cycle ended in the northeastern part of the continent with the onset of the compressional regime of the Grenvillian Orogeny sometime after 1200 m.y.

12. Projects Outside of Canada Undertaken at Canadian Institutions

(a) Low O^{18} basalts from Iceland; K. Meuhlenbachs (University of Alberta).

(b) Cretaceous and Tertiary volcanism in Jamaica; T.E. Smith (University of Windsor).

(c) Tertiary volcanism, Carriacou, West Indies; T.E. Smith (University of Windsor).

(d) Volcan Iztaccihuatl, central Mexico; G.T. Nixon (University of British Columbia).

(e) Late Cenozoic alkali basalts of Southeast Asia; S.M. Barr (Acadia University).

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VIII EXPLORATION GEOPHYSICS

Compiled by: G.F. West

1. Department of Energy, Mines & Resources
2. Ontario Division of Mines
3. University of Alberta
4. University of British Columbia
5. Université Laval
6. University of Manitoba
7. University of Toronto
8. University of Western Ontario
9. Bibliography

This section attempts to provide a listing of non-confidential research in exploration geophysics in Canada completed or in progress during 1975. The function of the report is to provide those interested with information about current research projects which have not yet reached the publication stage. It is not to provide statistical data on the amount of work going on. The report is definitely not comprehensive as all submissions are voluntary and several active groups did not report this year.

1. EMR (GSC) Division of Resource Geophysics and Geochemistry

(a) Regional Geophysics Program - Magnetics and Remote Sensing Section (P.J. Hood)

An annual review of trends and developments in mining geophysics was published in the Canadian Mining Journal for the twelfth year in succession by P.J. Hood. The review for 1975 contained tabulations of commercially-available airborne gamma-ray spectrometers and ground scintillation counters and spectrometers. A table showing the average costs per line mile for airborne geophysical surveys during the five-year period 1970-1975 was also included in the article.

- Aeromagnetic Surveys

A total of 80 total intensity aeromagnetic maps were published by the Geological Survey of Canada during 1976. Of these, 72 were one-mile and 8 were 1:250,000 aeromagnetic maps. The total line mileage of aeromagnetic intensity survey flown in Canada from 1947 to the end of 1976 is 4,802,695 line miles, of which 148,285 line miles were flown during 1976 and this has resulted in the magnetic survey coverage for Canada shown in Figure 1. Also included in Figure 1, is the shipborne coverage which resulted from the survey operations of the Canadian Hydrographic Service.

- Magnetic Anomaly Map of Canada (P.H. McGrath)

The third edition of the Magnetic Anomaly Map of Canada (GSC Map 1255A) will be published during the latter part of 1977. Also a pilot project has been undertaken to establish procedures for the production of a new one to one million series of regional magnetic maps.

- High Resolution Aeromagnetic Survey Project

The inboard vertical gradiometer system installed in the GSC Beachcraft aircraft by a group headed by P. Sawatzky, was extensively test flown in the Ottawa area during the summer of 1975. Two vertical gradient surveys were carried out to obtain experimental results for evaluation by L.J. Kornik and P.H. McGrath. The areas chosen for this purpose were in the White Lake area some 40 miles west of Ottawa in the Carleton Place

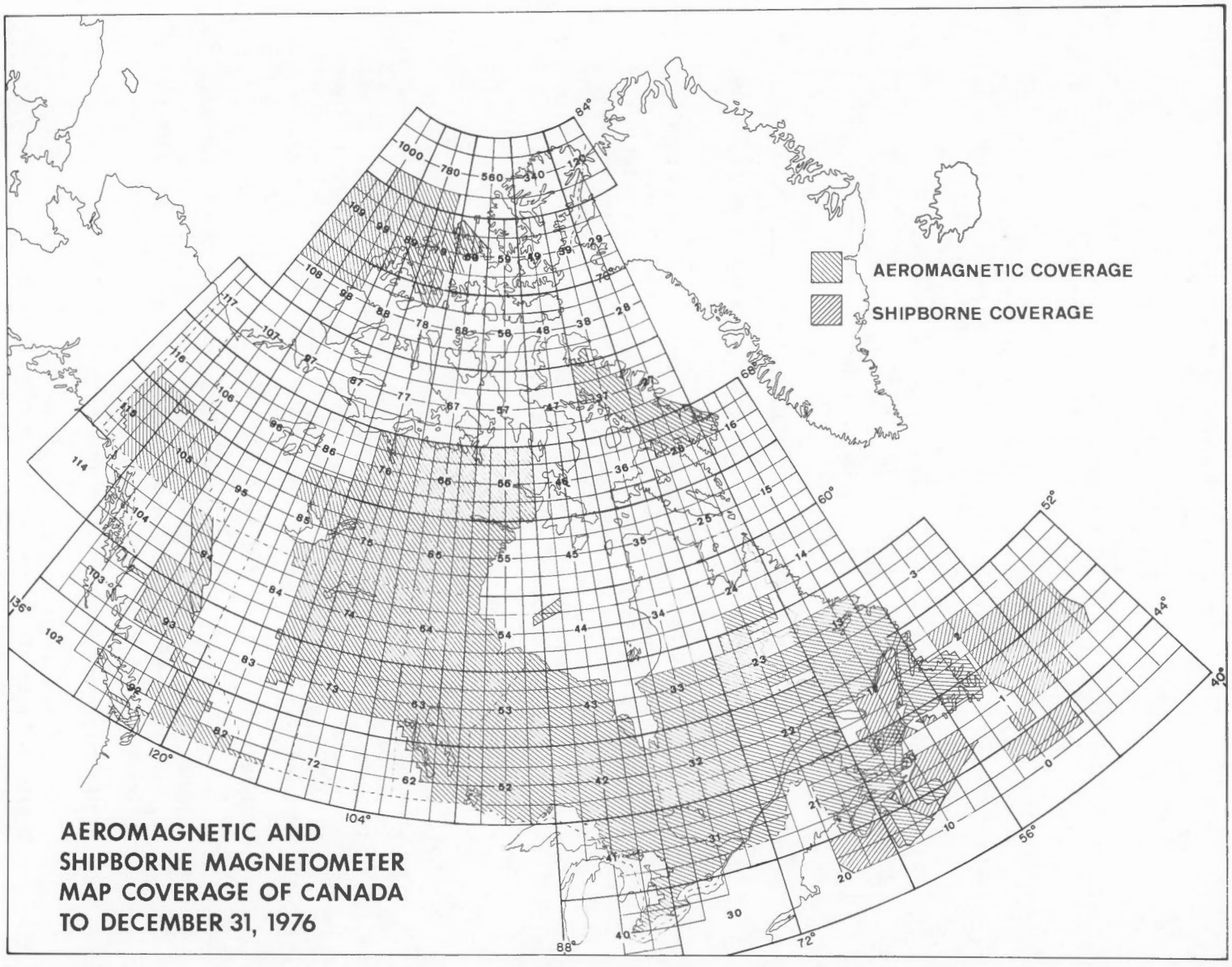
AEROMAGNETIC COVERAGE
SHIPBORNE COVERAGE
AEROMAGNETIC AND
SHIPBORNE MAGNETOMETER
MAP COVERAGE OF CANADA
TO DECEMBER 31, 1976

Figure 1.

area. To compile the gradiometer data, a new algorithm was developed by L. Kornik and S. Dods utilizing filtering procedures designed by P.H. McGrath. Four types of maps were prepared from the data for the White Lake Open File Release No. 339:

1. A total field map.
2. A residual total field map.
3. A calculated vertical gradient map.
4. A vertical gradient map.

The Carleton Place data will be published in two series of maps at the 1:25,000 scale: a total field map series and a new vertical gradiometer map series.

Results of these surveys show that more detailed information is contained in the vertical gradient map than in the other types of maps. Dykes, faults and other fine structures were recognizable in the vertical gradient maps and were correlatable with known geologic features.

Subsequently, during the summer of 1976, the gradiometer system was used to survey four additional areas:

1. Southern Vancouver Island including a portion of Juan de Fuca Strait;
2. An area north of Halifax, N.S.;
3. An area north of Truro, N.S.;
4. An area north of Yarmouth, N.S.

The data obtained from these surveys is in the process of being compiled. Also an area in Grimsthorpe Township which contains the Mt. Moriah syenite and part of the Tudor Gabbro was flown and compiled for the Radioactive Waste Disposal Project.

- Ocean Aeromagnetics

The cooperative aeromagnetic project with the National Aeronautical Establishment was continued during 1976 and survey operations were carried out in the North Atlantic Ocean, Caribbean Sea and Arctic Islands.

The objective of the North Atlantic and Caribbean flights was to obtain magnetic profiles over the geomagnetic anomaly centred in the vicinity of St. Croix Island. Lines were flown from Nova Scotia on the north to Republic of Guyana on the south and from Barbuda Island west to the coast of Belize. The observed data are being compared to the IGRF 1975.0 model of the earth's magnetic field and may eventually be used to modify the IGRF model. In the Arctic Islands, survey lines were flown in the Gulf of Boothia, Admiralty Inlet and north to Resolute Bay. These are regions of sedimentary rock that may be of interest for petroleum exploration.

These surveys were the last ones flown by the N.A.E. North Star; it is now being replaced by a Convair 580 which is expected to be in operation early in 1977.

- ERTS Imagery Evaluation (V.R. Slaney)

This project, in addition to building up a file of useable ERTS imagery of Canada, is being carried out to assess the geological applications of ERTS imagery and provide advice and assistance in its use.

(b) Seismic Methods Section (J.A. Hunter)

The results of the 3-year refraction seismic program in the Sverdrup Basin to map velocity-depth structure have been interpreted by A. Overton. The report is presently being prepared and the results will be placed in a GSC Open File Publication.

This project is carried out in cooperation with the Earth Physics Branch and the Institute of Sedimentary and Petroleum Geology to define the regional and structural geology of the coastal and continental shelf regions of Arctic Canada.

Shallow seismic refraction profiling was initiated at Rivière du Loup, Québec and Saint John, New Brunswick, as part of the GSC urban geological program. Approximately 400 profiles, outlining seismic horizons in unconsolidated overburden, were obtained. In addition, 9 boreholes were logged with gamma-gamma, neutron-gamma and seismic 3-component uphole tools in the Rivière du Loup area. The program will continue this year.

Shallow marine refraction profiling was obtained at Radstock Bay, Devon Island, N.W.T., as part of the CSS Hudson-76 cruise in Lancaster Sound. Depths to bedrock below seabottom were obtained at 80 locations in the vicinity of a proposed shipping terminal.

During the Hudson cruise, experiments were conducted with a 12-hydrophone 20 meter seabottom array to measure the compressional wave velocity of upper few meters of seabottom material. Six sites in Lancaster Sound were investigated in water depth up to 300 meters. Additional information was gathered at the sites utilizing the gamma-gamma, neutron-gamma and three gamma-ray spectrometer borehole tools.

In the Mackenzie Delta, borehole seismic tests were run in several shallow holes drilled in permafrost to determine the seismic velocities in a variety of ice-bonded unconsolidated materials. In addition, downhole shooting was conducted in three exploration wells in the Delta as part of a continuing program to measure seismic velocity anomaly associated with the permafrost section.

For the Beaufort Sea permafrost studies, the front ends of oil-industry reflection records have been used by H.A. MacAulay, K.G. Neave and J.A. Hunter to outline the distribution of ice-bonding in the sediments. Maps have been prepared which show the occurrence and the depth to the top of the ice-bonded layer. A further interpretation is being carried out to show the possible extent of a thin upper layer which is distinct from the main body of relic permafrost. Investigations are also under way into the reflection characteristics from the bottom of a very thick layer of permafrost. In addition, a region of marginally-bonded sediments, lying east of the Mackenzie Canyon, is being outlined because of its possible association with gas hydrate occurrences.

A hydraulic jet-drilling technique was developed which permitted the drilling of holes in permafrost, either sub-aqueous or sub-aerial, to depths of up to 60 meters. With this technique, thermistor cables can be installed in permafrost sections for determination of thermal profiles.

(c) Electrical Methods Section - Borehole Exploration (A.V. Dyck)

The evaluation stage of the borehole geophysics project to determine the state-of-the-art in commercially available exploration equipment was completed in 1976. The need for development of instrumentation and interpretation was recognized and a program initiated to satisfy the requirements. Efforts to date have been concentrated on the electromagnetic configuration of large-loop surface transmitter and

downhole receiver which had shown considerable promise during the earlier tests. It was also decided to proceed with borehole VLF EM as an effective yet inexpensive, simple device.

- Laboratory Investigations on Electrical Properties of Soils and Rocks (T.J. Katsube)

The frequency spectrum of the electrical properties of various rocks, minerals and soils are being measured over the frequency range from 10^{-2} to 10^{8} Hz. Several electrical models have been developed in an attempt to explain the electrical mechanisms involved. These models are represented by about 20 coefficients, and these coefficients are being used to characterize the rocks, minerals and soils. There are indications that these coefficients contain information on mineral type and content, rock texture, pore water content and structure, ice and clay content. This information, if successful in being extracted from electrical measurements, is thought to be useful for distinguishing between economic and non-econmic mineral deposits, measuring the porosity and permeability in rocks, and determining the soil moisture and ice content in soils. An effort is also being made to cooperate in establishing international standards for electrical measurements.

- Electrical Mapping Techniques (W.J. Scott)

During 1976 an interactive computer program was developed for interpretation of DC resistivity soundings. Many soundings from previous field work are being reinterpreted with the aid of the program.

A compilation is being undertaken of all the geophysical results available for the Involuted Hill Test Site on the Tuktoyaktuk Peninsula, N.W.T.

- Applied E.M. Problems (A.K. Sinha)

Quantitative interpretations of the Tridem airborne E.M. data over the Timmins area was done last year. It was observed that quantitative interpretation is feasible if all the six channels (3 in-phase, 3 quadrature) of data are usable. However, the data in the lowest frequency channel was very low, often below the noise level. After the high frequency noise and zero level errors were corrected, the data were interpreted to yield the thickness and resistivity of the top layer.

Theoretical studies on permafrost mapping by using multifrequency e.m. dipole sources were continued. The complete computer program for obtaining the electromagnetic response of an arbitrary n-layer lossy dielectric will be published as a G.S.C. paper in 1977.

Theoretical studies on the response of a layered permafrost medium when the frequency dependence of the layers have been considered were completed in 1976. The effect of the presence of a transition layer between the permafrost and the unfrozen ground was studied to see the possible errors that might be caused in neglecting its presence.

A study has been initiated to compare the effectiveness of several electrical and electromagnetic techniques for mapping the thickness and conductivity of overburden. For this, the field data obtained in one area by several techniques will be examined and interpreted for the final evaluation.

- Measurements of Soil Water Content in-situ (J.L. Davis)

Experiments are being carried out to determine:

(i) the relationship between the dielectric constant, in the frequency band of 1 MHz to 1 GHz, and soil water content;

(ii) if time-domain reflectometry techniques provide a practical method for measuring soil water content in-situ; and

(iii) if surface-borne radar techniques can be used to measure soil water content.

The studies are being carried out by J.L. Davis and A.P. Annan of the Electrical Methods Section of the GSC and G.C. Topp of the Soil Research Institute of Agriculture Canada.

Based on laboratory measurements with four soils, varying in texture from a sandy loam to a heavy clay,

(i) the real dielectric constant, in the frequency band 10^7 to 10^9 Hz, depends strongly on soil water content and weakly on other soil properties such as soil type, density and temperature;

(ii) an empirical relationship between the dielectric constant and volumetric soil water content can be derived; and

(iii) the dielectric constant in the aforementioned frequency range is a sensitive indicator of soil water content with a precision of ± 3 percent overall.

In the field the TDR technique provides a practical method of measuring soil water content. A microprocessor based system is being constructed which will allow a direct readout in the field of soil water content. Further laboratory and field experiments are planned to determine the reliability of empiracal relationship and the TDR technique under widely varying soil conditions.

Surface-borne radar techniques do give a measure of the dielectric constant and there is reasonable agreement with the TDR measurements. Further experiments are planned to determine the volume of soil sampled by the radar and to make the measurement technique more practical.

- Radar Sounding (A.P. Annan)

Ground probing radar is a relatively new geophysical technique. An extensive radar sounding project is currently underway at the GSC to

(i) assess and improve currently available instrumentation;

(ii) develop field methodology;

(iii) derive comprehensive interpretation schemes;

(iv) define geotechnical problem areas where radar can be beneficially employed.

During the past year the following field operations have been conducted in order to achieve these objectives.

(i) March and April (1976) were spent performing radar and time-domain reflectometry experiments at a variety of permafrost sites in

the vicinity of Norman Wells, Inuvik, Tuktoyaktuk and Rea Point, N.W.T., and Dawson City, Y.T.

(ii) Measurements of soil dielectric constant were made at a number of locations in the Ottawa area during July and August, 1976, in conjunction with the soil moisture program.

(iii) The electrical characteristics of the White Lake batholith were measured with a radar system in August, 1976.

(iv) Radar was used to experimentally sound water depths in the Rideau canal during September, 1976.

All field measurements were made using a Geophysical Survey Systems Inc., impulse radar system. The frequency ranges investigated were 50 to 150 MHz and 400 to 700 MHz.

Interpretation and data processing methods are currently under development in the laboratory. Main areas of work are:

(i) first pass interpretation of spring permafrost data and correlation of the interpretation with geologic control;

(ii) digitization of analog magnetic tape records for computer processing;

(iii) development of computerized $T^2 - X^2$ processing for wide angle reflection and refraction sounding surveys;

(iv) theoretical comparison of maximum range and resolution of currently available ground probing radar;

(v) numerical simulation of the transient radar response of a lossy dielectric earth in order to use signal amplitude in interpretation;

(vi) development and testing of digital data enhancement processing such as hyperbolic stacking and deconvolution for radar data.

While most of the experimental data is still being interpreted and interpretation techniques are still in the development stage, some conclusions drawn from the work to date are:

(i) radar can be used to map lithology in frozen coarse-grained soils (interfaces at depths exceeding 30 m have been mapped);

(ii) frozen, fine-grained soils exhibit significantly higher electrical loss than frozen, coarse-grained soils (in clay covered areas, penetration of radar signals was less than 3 m);

(iii) ice thickness on fresh water lakes and rivers can be mapped quickly and routinely;

(iv) fresh water river and lake bottoms have been detected and mapped in water depths of up to 7 m;

(v) digital data enhancement techniques significantly improve the interpretation of the data.

Future plans involve continued interpretation and processing of available data plus further field experiments. Field plans for 1977 include work in the potash mines in Saskatchewan and borehole experiments in massive rock formations. Personnel involved in this project are A.P. Annan, J.L. Davis and J. Lobach.

(d) Resource Evaluation Program - Radiometric Section (K.A. Richardson)

- Contract Surveys (J.M. Carson)

In 1976, the second year of the Federal Provincial Uranium Reconnaissance Program, approximately 100,000 line kilometres of high sensitivity airborne gamma-ray spectrometry data were collected. Surveys were flown with 5 km. line spacing in New Brunswick, Ontario, Manitoba, Saskatchewan and Northwest Territories. The locations of these survey areas, and the status of reconnaissance airborne radiometric coverage are shown in Figure 2. Results of the 1976 surveys will be published in the spring of 1977.

- Skyvan Surveys (P.B. Holman)

In addition to the above contract surveys, the G.S.C. Skyvan carried out more detailed airborne radiometric surveys over the northeastern extension of the Wollaston Fold Belt, from Saskatchewan, through northwestern Manitoba into the Northwest Territories, and in the Tatamagouche, Uniacke and Kennetcook map sheets of Nova Scotia. Reconnaissance surveys were flown by the Skyvan in Southern Nova Scotia, the Kingston to Bancroft area of Ontario and the Cypress Hills in Saskatchewan.

- Evaluation of Uranium Reconnaissance Radiometric Program Data (B.W. Charbonneau)

In 1976 follow-up investigations took place principally in Northern Manitoba and to a lesser extent in Northern Saskatchewan. The ground work generally consisted of gamma-spectrometry, scintillometry, sampling and some geological mapping. Some 20 individual radiometric anomalies were evaluated on the ground as well as one block between Snyder Lake and Kasmere Lake in Northern Manitoba. The individual anomalies investigated generally related to granites and/or pegmatites with above normal uranium concentrations. Within the block area uranium mineralization was found to relate to: (a) pegmatites, (b) fractures and (c) to have broad stratigraphic control. This area has been the site of extensive exploration activity by industry following the release of the 1975 government radiometric and geochemical survey data.

Additional ground investigations took place in the Pembroke area N.T.S. 31F, and in Prince Edward Island where a truck-borne spectrometer survey was made following the reconnaissance airborne survey of the Province.

- Nuclear Borehole Geophysics, Gamma-Ray Spectrometric Borehole Logging (P.G. Killeen)

A backpack portable gamma-ray spectral logging system with digital recording was successfully assembled and field tested in 1976. A truck mounted digital logging system has been designed and will be field tested in the summer of 1977. The 'DIGI-PROBE' logger (Digital Processing of Radiometric Observations in Borehole Environments) will serve as an R&D system to develop new data acquisition and processing techniques for borehole geophysics. Model boreholes are under construction (completion in July 1977) at Bells Corners near Ottawa for calibration of gamma-spectral logging systems.

- Gamma-Ray Spectrometry Instrumentation (Q. Bristow)

The high sensitivity airborne system, used by the G.S.C. since 1967 has been updated. Twelve 4x4x16 prismatic NaI detectors will be used lying side by side in a single container, each one being fitted with a

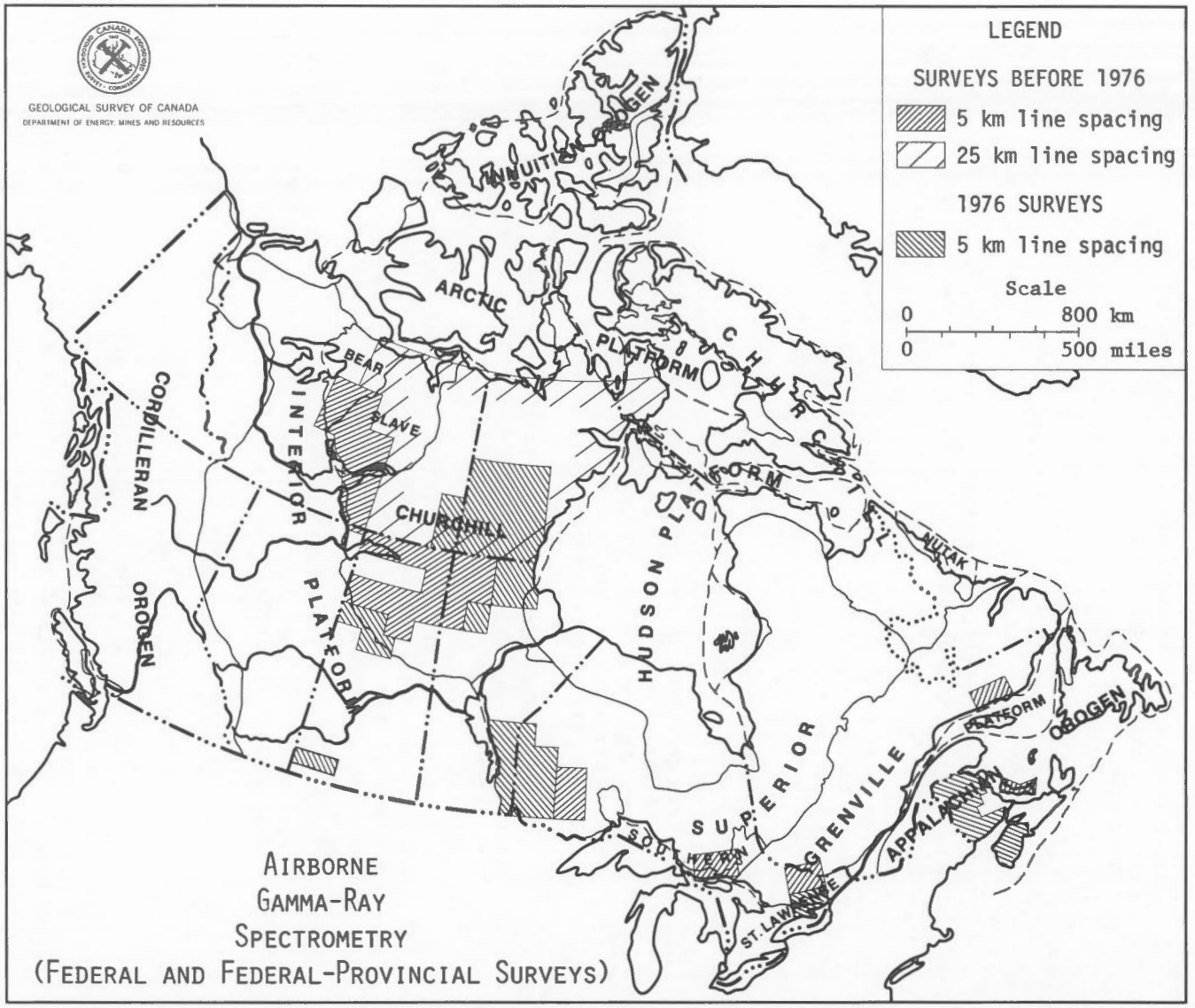
GEOLOGICAL SURVEY OF CANADA
DEPARTMENT OF ENERGY, MINES AND RESOURCES
LEGEND
SURVEYS BEFORE 1976
5 km line spacing
25 km line spacing
1976 SURVEYS
5 km line spacing
Scale
0 800 km
0 500 miles
INUITIAN OROGEN
ARCTIC PLATFORM
CHURCHILL PLATFORM
BEAR
SLAVE
INTERIOR
CORDILLERAN OROGEN
PLATFORM
HUDSON PLATFORM
NAIN
NUTAK
SUPERIOR
GRENVILLE
PLATFORM
OROGEN
APPALACHIAN
ST. LAWRENCE
AIRBORNE
GAMMA-RAY
SPECTROMETRY
(FEDERAL AND FEDERAL-PROVINCIAL SURVEYS)

Figure 2.

D.C. coupled preamplifier designed by the author, which improves immunity to cosmic overload pulses and problems caused by high count rates, by eliminating pulse undershoot. A Data General NOVA 1220 minicomputer is used for data acquisition and control together with a 9 track tape transport, a Texas Instrument Silent 700 data terminal and a display designed around a Tektronix 604 monitor with both text and spectrum display modes. Complete spectra will be recorded with the new system to provide data for an ongoing research programme in airborne gamma ray spectrometry.

An identical data acquisition and control system is being mounted in a truck for use in a borehole gamma ray spectrometry research programme, resulting in a high degree of hardware/software compatibility between the two systems.

2. Ontario Division of Mines

(a) Gravity

A gravity-magnetic susceptibility survey over the Red Deer metavolcanic metasedimentary belt, District of Kenora was carried out during the summer of 1976 (Gupta & Wadge, 1976). The objectives of the survey were to outline the deeper geological and structural characteristics of the belt to permit interpretations of its configuration in the third dimension and to collect data on the magnetic susceptibility of the various rock units for improved interpretation of aeromagnetic data. Details are given in the gravity section.

(b) Exploration Geophysics

A reconnaissance airborne gamma-ray spectrometer survey for uranium has been conducted in the Dryden-Deer Lake area, Districts of Kenora and Rainy River as part of the joint Federal-Provincial Reconnaissance Program. The results of a Federal-Provincial airborne gamma-ray spectrometer survey in the Ignace-Sioux Lookout area, Districts of Kenora and Thunder Bay were released in June of 1976.

The results of a residual, low level magnetometer survey covering approximately 500 square km in the Bamaji-Fry Lakes area, District of Kenora were released in the spring of 1976.

A program to contract geophysical surveys including ground resistivity and airborne electromagnetic surveys to test methods for lignite exploration were carried out over the Omakawana lignite deposit of the James Bay Lowlands, District of Cochrane.

The results of these test surveys have been released in the Ontario Division of Mines Open File Report 5196, Report on Geophysical Survey, Omakawana lignite fields, District of Cochrane.

3. University of Alberta, Geophysics Lab, Department of Physics

Interpretation of Direct Current Resistivity Measurements (D.W. Oldenburg)

The theory of Backus and Gilbert has been used to invert the potential differences measured in direct current resistivity soundings. It is assumed that the resistivity is isotropic and a function of depth only. An iterative technique has been developed whereby potential differences from any electrode configuration can be inverted to construct a resistivity whose predicted responses are in agreement with the observations. Convergence of the iterative scheme is very rapid. The problem of non-uniqueness is solved by using the observations to provide information only about the average of the resistivity around any depth of interest. Knowledge of the Frechet kernels

for the resistivity problem allows one to compare for the first time the resolution provided by different electrode configurations and to explore the possibility of designing the locations at which surface measurements are taken in an attempt to optimize the resolution of the resistivity at any depth.

4. University of British Columbia, Department of Astronomy

(a) Communication Theory and Data Analysis (G.G. Fahlman, T.J. Ulrych, R.W. Clayton and L.R. Lines)

T.J. Ulrych and G.G. Fahlman continued to study the use of the maximum entropy spectral estimator for data which contains gaps which are long compared to the length of individual data segments. A successful approach has been found. The gaps are filled by minimizing the prediction error in a gap with respect to the unknown data values. The prediction error is based on a filter that is computed in the usual way using only the known data segments. Once the gaps are filled, the MEM spectral density is estimated from a new filter computed from the observed and predicted data values.

R.W. Clayton, T.J. Ulrych, and L.R. Lines have applied the MEM/AR modelling technique to the problem of enhancing the resolution of impulsive functions that have been degraded by a convolutional disturbance and by the addition of white noise. Specifically the method has been applied to the deconvolution of Vibroseis reflection data and to the resolution of overlapping spectral lines.

5. Université Laval, Département de Géologie

Méthodes électriques et thermiques:

(a) Région de la Rivière Georges

M.K. Séguin a effectué des travaux archéophysiques dans la région de Mushua Nipi, extension sud des Torngats (64°W, 57°N) en collaboration avec G. Samson (archéologue) et S. Martel (étudiante sous-graduée). A l'aide de techniques de résistivité électrique de surface (profilages et sondages) on a pu déterminer la nature de l'érosion du lit de la rivière Georges, l'épaisseur et la nature des 5 terrasses sur lesquelles se trouvent les sites archéologiques, l'épaisseur du molisol et du pergélisol discontinu. Après avoir obtenu la signature électrique caractéristique de structures historiques et préhistoriques telles que tentes, tour d'observation, bains, etc., on a pu déceler les structures cachées en comparant ces signatures.

(b) Région de la Rivière de Feuilles (73°W, 59°N)

M.K. Séguin a entrepris une étude permettant d'établir la relation entre le pergélisol discontinu et la végétation (type et quantité). Ce travail a été effectué en collaboration avec un écologiste (S. Payette) et une étudiante sous-graduée (S. Martel). A l'aide de sondages de résistivité électrique a très basse fréquence (ELF, 4 Hz) on a établi une relation entre l'épaisseur de pergélisol et les peuplements de mélèzes d'épinetière ou mixtes, les buttes minéralogènes boisées ou non boisées, les mares et les vallées de ruissellement. Excepté en bordures du socle rocheux, on observe une moins grande épaisseur de pergélisol dans les régions boisées que dans les régions non boisées. L'épaisseur du pergélisol est moindre dans des peuplements de mélèzes a proximité d'étendues d'eau et de mares que dans des peuplements d'épinettes. On n'observe presque pas de pergélisol dans les rigoles de ruissellement.

(c) Région de Purtuniq (Asbestos Hill)

Les travaux effectués par M.K. Séguin et collaborateurs (P. Champagne, étudiant en maitrise, R. Robitaille, étudiant sous-gradué) comportent deux aspects: a) carte géomorphologique du glaciaire et du glaciel accompagnée de sondages et de profilages électriques de surface b) étude du pergélisol continu dans des trous de forage.

En plus d'une carte géomorphologique couvrant quelque 600 Km^2 dans la région de Purtuniq (75°W, 62°N), on a effectué des travaux additionnels dans les secteurs des lacs Watts et Duquette (Otter). Les travaux de résistivité électrique avaient pour but de déterminer l'épaisseur des blocs gélivés, des étages de replats Goletz, des nappes et lobes de solifluction, des depots fluviatiles et du mollisol.

L'étude du pergélisol continu a consisté en des mesures de résistivité électrique, du potentiel spontané et thermique dans des trous de forage a partir de la surface ou d'une galerie souterraine. On a essayé d'établir une relation entre le potentiel spontané et la résistivité électrique d'une part et la température d'autre part. Il semble en effet y avoir une relation assez claire dans l'étendue 0 à -3°C. A des températures plus basses, il appert que la résistivité électrique demeure a peu près constante. L'épaisseur de pergélisol continu est de l'ordre de 275 à 300 m et les températures minima d'environ -9°C sont courantes.

6. University of Manitoba, Department of Earth Science

(a) Test Site (C. Anderson)

The University of Manitoba has established a test site for ground geophysical prospecting systems at Banbee Lake, Ontario. There are three shallow EM conductors due to barren sulphides in the area.

7. University of Toronto

(a) Magnetometric Resistivity (MMR) Modelling (E. Gomez-Trevino and R.N. Edwards)

An inexpensive, rapid method has been developed for computing all three components of the magnetic field due to galvanic current flow from a point electrode in the vicinity of a conductive anomaly of infinite strike length and arbitrary cross-section.

For any three-dimensional structure, the magnetic field may be written as a sum of surface integrals over boundaries defining changes in conductivity by a direct modification of the Biot-Savart law. The integrand of each surface integral includes the components of the electric field tangential to the boundary which may be evaluated on the boundary using a standard integral equation technique.

In the case of a two-dimensional structure, a reformulation of the theory, by taking a one-dimensional Fourier transform along strike, results in the reduction of the surface integrals necessary to solve the integral equation for the electric field, and those used in computing the magnetic field, to line integrals in wave number domain. We evaluate the integrals numerically and solve an integral equation numerically for each of about ten wave numbers and obtain the magnetic fields in space domain through a concluding one-dimensional numerical inverse Fourier transform.

Solutions obtained with the method have been checked against known responses of simple geometric structures.

The detectability of a buried vertical dike of finite depth extent and thickness has been studied in detail. Type curves and some characteristic curves were computed.

(b) Electrical Sounding in Permafrost and Glaciers (D.W. Strangway, A. Koziar, J. Rossiter, J.D. Redman and J. Wong)

Work on permafrost sounding was extended this year to include measurements by audiofrequency magnetotellurics (AMT), radio frequency interferometry and in-situ probes to study the electrical structure in winter time. Previous work using AMT in the summer time suggested that the active layer was transparent. The winter time results were essentially unchanged and confirm that AMT sounding is an excellent method for determining permafrost thickness even in the presence of the active layer. The radio frequency interferometer sounding data showed also that the active layer had little influence on the results but that attentuation due to the properties of the permafrost itself reduced the interference to a very low level. This means that this method can only be used in high resistivity permafrost (10^4 ohm-m or more). At the same time, the measurement of the dielectric properties in the top meter of the soil showed marked changes between summer and winter due to the presence of moisture and clays. These data could be explained from the previously studied properties of permafrost as a function of temperature.

These results were presented at a conference on Water in Planetary Regoliths held in Hanover, N.H. A model to describe scattering in various glaciers and in permafrost is nearing completion and will be incorporated in Rossiter's Ph.D. thesis.

(c) Crustal Sounding by Audiofrequency Magnetotellurics (D.W. Strangway, J.D. Redman and A. Kryzan)

Crustal sounding work was continued this year with two major new field studies. A regional study of the electrical structure in the Precambrian of the upper peninsula of Michigan was carried out. This study adds to our previous studies in Nevada, New Mexico and Wisconsin done as part of Project Seafarer for the U.S. Navy. We also completed a major survey in the Geotraverse area of northern Ontario paying special attention to differences between granites, gneisses and greenstone belts. In general, it can be said that the pattern of a highly resistive layer (up to 100,000 Ohm-m or more) in the top few kilometers of the crust is typical of shield areas. Beneath this, the resistivity drops sharply, suggesting the presence of moisture in the middle crust. This work was presented at a crustal workshop held in Vail, Colorado. It appears that these low resistivities are correlated with low velocity and low Q portions of the crust.

(d) Electrical Properties of Rocks - Terrestrial and Lunar (D.W. Strangway, S. Nowina, J. Wong, J.R. Rossiter and G.R. Olhoeft)

This is a continuing program of electrical property studies. We are continuing to examine the implication of the measured electrical properties of lunar samples on the nature of planetary sounding. This work is interpreting the radar returns from the planets and radio-frequency sounding results carried out on the moon. These results are explainable in terms of highly transparent materials which become highly scattering at high frequencies. Some results were presented at the Conference on Water in Planetary Regoliths.

Using the high vacuum system, Mr. Nowina has made measurements of the intrinsic dielectric anisotropy of a number of Precambrian samples from deformed regions of the shield. Using a simple model of series and parallel paths these properties can be quite readily described and clearly

reflect the strain in the rocks. Analogous measurements of the magnetic susceptibility anisotropy give similar results.

A new effort to study the electrical properties of interfaces has been initiated. This effort will concentrate on the interface between semi-conducting solids and between semi-conductors and fluids.

(e) Magnetic Mapping (D.W. Strangway, A. Gubins and J. Bambrick)

Two projects are now under way. The first of these is an M.Sc. study by Mr. Gubins on magnetic gradiometry. He is developing interpretive techniques and has applied these to a number of examples. He takes delivery of a prototype gradiometer in January which will be used for a number of studies including mapping of ancient meteorite crater features. The second project is just getting started and involves an attempt to study the magnetic signatures found within a greenstone belt. These signatures will be correlated with a number of geological and geochemical parameters.

(f) E.M. Prospecting (G.F. West, Y. Lamontagne, G. Lodha and J. Macnae)

A time-domain ground EM system known as UTEM was developed in 1974-5 chiefly as the Ph.D. project of Y. Lamontagne. Initial tests with the system showed that it may have considerable capabilities in deep prospecting and in sorting out situations which are difficult and/or complicated for standard EM methods. It is also a very valuable research tool for investigating the true electrical characteristics of actual geological conductors, information which is essential to designing instrumentation and interpretation techniques for routine EM prospecting.

The research program is being carried on by Lamontagne assisted by graduate students G. Lodha and J. Macnae. A new version of the UTEM instruments has been designed and constructed in cooperation with Geonics Ltd. The new system has improved characteristics over the original crude prototype and includes digital data acquisition on tape and a playback-calculator-plotter system for use in the field camp. A series of detailed investigations of known EM targets has begun using the UTEM instruments and other survey data provided by mining companies. Three site studies were completed by the end of 1976.

On the theoretical side, computer model studies have been done and additional studies are underway to intercompare the response characteristics of a variety of time and frequency domain EM systems and to provide interpretational tools for the UTEM investigations. The first modelling program was carried out by G. Lodha and is an implementation of a basic algorithm devised by P. Annan for calculating the response of a thin plate. The present modelling routine permits calculation of time or frequency domain response for any type of loop-loop EM system.

Detailed interpretation of the site surveys is being carried out by Macnae, Lodha and Lamontagne. The initial surveys immedately emphasize the very great diversity in the electrical and geometrical characteristics of various types of target mineralization.

8. University of Western Ontario, Geophysics Department

(a) Time Series Analysis in Vertical Electrical Sounding (VES) (Seara and Mansinha)

A major recent development in the interpretation of vertical electrical sounding data has been the application of the techniques of Fourier transforms. With the Fast Fourier algorithms one can now compute VES master curves for various models speedily and inexpensively. We have

been experimenting with various types of digital filters to aid in the interpretation.

(b) Mise A La Masse Modelling by the Finite Element Method (Mwenifumbo and Mansinha)

The Mise a la Masse technique has been successfully employed in electrical potential surveys and has sometimes been used in grounded cable EM surveys to try and enhance the response of the deeper extensions of orebodies. Little attention has been paid towards a quantitative analysis of the data. The finite element method is being applied to modelling this method and developing an interpretation technique.

(c) A Gamma-ray Spectrometer Survey of Two British Columbia Porphyry Ore Deposits (Mathews and Hayatsu)

Two major British Columbia porphyry copper ore bodies were surveyed using the gamma-ray spectrometric technique in order to establish potassium, uranium and thorium abundance and distribution. Similar work undertaken by Davis and Guilbert in the southern United States showed very distinctive potassium and thorium distribution reflecting the hydrothermal alteration of the deposits. This pattern of potassium enrichment and thorium depletion is not so clearly exhibited in the two B.C. deposits unless irregularities of short wave lengths are removed.

(d) Statistical Analysis of P-Wave Anomalies and the Study of Lateral Inhomogeneities (Waboso and Mereu)

Observed P-wave amplitude and travel-time anomalies are due to scattering by random inhomogeneities in the crust and upper mantle.

A new "Block" model introduced by Aki et al. (1975) for the statistical analysis of these anomalies suggests a useful tool for obtaining more detailed information on the nature of the inhomogeneities. This model is being examined with respect to the dependence of solutions on model parameters like block size and configuration, number of layers considered, area covered etc.

The objective is to adapt the analysis to the mapping of local anomalous bodies such as sulphide bodies or gravel deposits.

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IX GLACIER STUDIES

Compiled by: C.S.L. Ommanney

1. Energy, Mines and Resources
   (a) Geological Survey of Canada, Ottawa
   (b) Polar Continental Shelf Project
2. Environment Canada
   (a) Applied Hydrology Division
   (b) Glaciology Division
3. National Defence
4. K.E. Ricker Ltd., Vancouver
5. University of British Columbia, Vancouver
6. University of Colorado, Boulder, Colorado, U.S.A.
7. McGill University, Montreal and E.T.H., Zurich
8. University of Minnesota, Minneapolis, U.S.A.
9. Canadian Exploration Group, Peterborough, Ontario
10. Bibliography

1. Energy, Mines and Resources

(a) Geological Survey of Canada, Ottawa

Submarine observations of three calving glacier fronts, south Devon Island (B.D. Bornhold, S.M. Blasco and P. McLaren) - Studies in Cuming Inlet and Croker Bay focussed on the marine margins of three small outlet glaciers of the Devon Island ice cap. Sidescan sonar, grab sampling, coring, suspended particulate matter collection and diving observations were carried out. Sidescan sonar profiles parallel to the ice fronts revealed fissures extending more than 75 m into the ice and ledges of ice several tens of metres long. Poor visibility and deep water precluded abundant observations of the glacier margins. In all cases a very steep ridge of unstable boulder moraine was parallel to the ice front. The proximal and distal slopes were approximately 45°. The seaward slope was mantled with silt derived from the release of rock flour from the melting glacier ice. The area of active sedimentation was small.

(b) Polar Continental Shelf Project (R.M. Koerner)

Meighen Island Ice Cap - The 1974-75 annual mass balance was 5.4 g/cm^2 and the winter 1975-76 balance, measured in mid-June was 15.1 g/cm^2. Bad weather precluded measurements on Melville Island.

Devon Island - The mass balance for the Devon Island Ice Cap for 1974-75 was -6.9 g/cm^2. The mean net balance for the 14 years 1961-75 is -6.7 g/cm^2. A final set of inclinometer measurements was made in the 1971 and 1972 boreholes. P. Winter, Earth Physics Branch, EMR, repeated gravity ties between the borehole site and Resolute Bay, first made in 1971, and found no change in ice thickness.

During June a program to measure the sonic (high-frequency seismic wave) velocity in the boreholes was carried out by the University of Wisconsin (C.R. Bentley). In the 1971 hole only a short section, between depths 151 and 178 m, could be logged. In the 1972 hole, with less closure and a higher fluid level, the depth range between 80-270 m was successfully logged. The normal increase of velocity with depth was observed to 210 m. At greater depth it decreased rapidly downward, a completely unexpected result. Velocities were less with short receiver spacing than with long and most were substantially less than would be expected in solid ice of any fabric indicating a decreasing effect of closure with distance from the hole. The flow of ice around the hole seems to have rotated the ice crystal orientation to a substantial inclination and cracked the neighbouring ice. Travel times were used to

determine changes in the 1972 hole diameter. There is a linear decrease in radius to 120 m (5 mm), no change from 120-210 m, and a linear decrease, totalling 13 mm, from 210-270 m. It also appears that there are decompression effects which have changed the densities in the core relative to those in situ.

Field trials and measurements were made on the ice cap with a new Phase-Sensitive Radio Echo sounder by a three-man team from Bristol University (M.E.R. Walford). The main objective, successfully completed, was to measure the amplitude and phase of radio echoes returned from the bed of the ice cap. It was observed that return echoes contain many dislocations of the type previously observed in pulsed wave trains in the laboratory that may be useful in relocating experimental sites precisely. Echoes can be detected using a receiving antenna oriented at right angles to the transmitting antenna. The depolarized signal is of the order of 10 dB down on the usual signal. It is hoped that techniques can be developed for synthesizing amplitude-phase information from a network of closed-spaced radio-echo sites.

Radio echo sounding - Using a 620 MHz (Goodman) high resolution echo-sounder 4 ice caps were sounded in a search for a 1977 borehole site. In transects down the S and NW sides of the Devon Island Ice Cap depths were of the order of 300-700 m, the thicker ice being on the S side. The 6 x 3 km grid on a central Ellesmere Island ice cap with transects E down Cadogan Glacier and W revealed ice thickness much greater on the E side with the bed of the glacier below sea level for several km. The 14 x 15 km grid on Mer de Glace Agassiz (N. Ellesmere) showed rugged bedrock topography with ridges parallel to those exposed. Depths range from 100 m on the latter to 800 m in the valleys. Soundings on the top of the main Axel Heiberg Island ice cap revealed very rugged, mountainous, topography under the ice with depths from 100-700 m. Ice depths on the W side (Thompson Glacier) were 400-500 m compared to about 200 m on the E side.

Mass Balance - Low-order accuracy mass balance networks were set up across the central Ellesmere Island ice cap and down the E side of the Axel Heiberg Island ice cap to provide background data for possible future boreholes.

2. Environment Canada

(a) Applied Hydrology Division (I.A. Reid and J.O.G. Charbonneau)

Glacier Survey, Western Canada - During August the Bugaboo, Sphinx and Nadahini glaciers were surveyed by terrestrial photogrammetry. The Sentinel and Kokanee glaciers were completely snow covered and not surveyed. The Water Survey of Canada in Calgary (L Warner) surveyed the Saskatchewan and Athabasca glaciers.

(b) Glaciology Division (D.K. MacKay, A/Chief)

Glacier Inventory of Canada (C.S.L. Ommanney) - Reduced manpower resulted in somewhat limited progress on the basic glacier inventory in 1976. The inventory of the St. Elias Range is being extended to the northern Coast and Boundary Ranges (S.G. Collins); that covering Yoho National Park is about 50% complete. Bibliographies covering the St. Elias, Glacier and Mt. Revelstoke National Parks, Mt. Robson Provincial Park, the Columbia Icefield, rock glaciers and ice core drilling are being compiled. Arrangements have been made for Canadian co-operation with and input to the Temporary Technical Secretariat for the World Glacier Inventory in Zurich.

Aerial Photography (K.C. Arnold, D.A. Sherstone and A.C.D. Terroux) - With Polar Continental Shelf Project support and a Wild RC-10 aerial camera two ice caps near Grise Fiord, Ellesmere Island, were photographed. The annual coverage of selected glaciers on this and Axel Heiberg Island was prevented by poor weather.

Barnes Ice Cap, Baffin Island (G. Holdsworth) - Three continuously recording 5 m wire strain meters (Cambridge type) were installed at several sites within the South Dome surge area (K. Evans, Cambridge University). Strains over 5 m gauge lengths generally showed a smooth behaviour and at one site a quasi-periodic variation (11 day period) seems to exist independent of temperature or pressure changes. Strains over the various 50 and 500 m lines measured concurrently during a three week period in May were irregular, even considering the much larger errors in measurement involved.

Mount Logan, Yukon Territory (G. Holdsworth) - Semi-final preparations were made for a 1978 core drilling on the NW col as part of a climatic change study. Two 8 m cores were taken to substantiate results for the 1975 16 m core. Ice depths were obtained along a traverse up to the NW col, in conjunction with U.B.C. (G.K.C. Clarke and B.B. Narod).

Glacier Mass Balances: Western Cordillera (O. Mokievsky-Zubok) - Measurement of winter and summer balances continued on Place and Sentinel, two former IHD glaciers. Helm Glacier was added in 1975. Specific net balances were +0.87, +1.48 and +0.57 m H_2O respectively. Summaries of measurements for the IHD period on Place and Sentinel glaciers, bibliographies and references to special studies are in press.

Hydrochemical Model of Glacier Meltwater (O. Mokievsky-Zubok) - In cooperation with the Water Quality Branch (J. Zeman), the hydrochemistry of the Sentinel Glacier basin was investigated to determine the characteristics of various glacier meltwaters and to develop a regional classification.

Role of Glaciers in Water Management in Remote Basins (O. Mokievsky-Zubok) - Three glaciers covering an area of 120 km^2 at the headwaters of Bridge River, B.C., were studied to determine the effect of glaciers on overall drainage basin runoff and to evaluate seasonal and operational forecast models for a downstream hydro-power reservoir. The glaciers "Bridge", "Sykora" and "Zavisha" had positive net balances of +0.83, +0.83 and +1.10 m H_2O respectively.

Glacier Mass Balances: Eastern Cordillera (G.J. Young) - A basic monitoring of mass balance, stream flow and local meteorology was continued on Peyto Glacier. The program on Woolsey and Ram glaciers has been terminated.

Glacier Hydrology (G.J. Young) - In conjunction with the continuing studies on Peyto Glacier a wider ranging investigation of the influence of glaciers on alpine stream hydrographs has been initiated in Yoho National Park. The hydrology and climatology of several small catchments (some glacierized, others ice free) are being monitored to assess seasonal and daily contributions of glacier melt to stream flow.

Peyto Glacier Map (W.E.S. Henoch) - A new multi-coloured edition of the Peyto Glacier map with shading, bedrock portrayal and interpretive text was produced at a scale of 1:10,000. The map combines accuracy and artistry to satisfy needs ranging from glaciological research to tourism.

3. National Defence

(a) Laboratories of ex Defence Research Board (H. Serson)

Ward Hunt Ice Shelf Survey - The Ward Hunt Ice Shelf and Ice Rise networks were remeasured between June 16 and 17. Positive net balances were +0.001 for the former and +0.039 m H_2O for the latter. There was further indication that the large variation in the Ice Shelf data may be caused by periodic filling and draining of the troughs.

Ellesmere Island Studies related to Climatic Change (H. Serson) - On June 11 the accumulation network of the small ice cap near St. Patrick's Bay was measured and a negative net balance of -0.072m H_2O for 1975-76 found.

4. K.E. Ricker Ltd., Vancouver

Yukon Resources Atlas (with F.F. Slaney & Co. Ltd.) - The acquisition of bibliographies and follow-up illustrations for each scientific endeavour on the 1:250,000 basemaps was concluded in 1976. The Atlas plates on meteorology, hydrology and glaciology, Quarternary geoscience and hydroelectric development will be of interest to glaciologists. The project will probably be published in late 1977 or early 1978.

Tchaikazan Valley glaciers, Coast Mts., B.C. - The 1975 field work was analyzed and published in the Canadian Alpine Journal.

Wedgemount Lake and Glacier, Coast Mts., B.C. (with W.A. Tupper) - All available aerial photography was reviewed for mapping. Control was established around the lake and terrestrial photogrammetry used to define the snout position. The glacier is still receding catastrophically, calving being the dominant process. Several moraines were identified and lichenometric measurements and dendrochronologic samples taken from each where available. Conifers on the climax distal morain were slightly <50 years old though a 1951 moraine has yet to be colonized by woody species. Wedgemount Lake was sounded (max. depth slightly >60 m). The basin shallows markedly to the snout indicating a grounded tongue. A bathymetric map is being prepared and calculations made of volumetric ice loss from 1927 to 1976.

5. University of British Columbia, Vancouver

(a) Department of Geophysics and Astronomy (G.K.C. Clarke)

Hazard Glacier, Yukon Territory (with S.G. Collins, J.G.P. Napoleoni and B.B. Narod) - Three holes, presumed to have reached the glacier bed, were drilled using a new hot water circulating drill. The deepest hole was 220 m and the maximum drilling speed 120 m/hr. The holes were instrumented with thermistor cables to allow future temperature measurements. A levelling survey was completed. Hazard Glacier is a surgetype glacier so these measurements are of particular interest.

Radio Echo Sounding of Yukon Glaciers (with B.B. Naord) - Airborne surveys of the Backe, Hazard, Rusty and Trapridge glaciers were carried out using U.B.C.'s 840 MHz sounder. A single traverse was also flown over the NW col of Mt. Logan to aid in site selection of a corehole to extract the oxygen isotope record of climatic change.

(b) Department of Geology (W.H. Mathews)

Berendon Glacier (with O. Mokievsky-Zubok, Glaciology Div.) - Using electromagnetic detectors, tuned accumulation markers were relocated, ablation measured and stake movement determined on the south arm of Berendon Glacier.

Glacial Abrasion - Experiments have been initiated on simulated glacial abrasion using a grindstone of ice plus crushed quartz turning slowly in a deep-freeze between stone plates.

6. University of Colorado, Boulder, Colorado, U.S.A.

(a) Institute of Arctic and Alpine Research (R.G. Barry)

Glacier Studies, Auyuittuq National Park, Baffin Island - With support from Parks Canada, INSTAAR supervised the installation of two long-term climatological stations in the Park and trained wardens in the basic observation routines and mass balance measurements. Stake networks were installed on "Boas Glacier" (46204J-68) and "Ugaliq Glacier" (46204D-87).

Neoglacial Moraines, Baffin Island - Lichenometric and weathering data were collected from Neoglacial moraines near Pangnirtung as part of a continuing study of Late-Holocene glacial chronology (P.T. Davis). Replicate coring of sediments in two lakes was carried out, spanning the last 5000 years.

7. McGill University, Montreal and E.T.H., Zurich, Switzerland

(a) Departments of Geography (F. Muller)

Automatic Weather Stations, North Water - Six unmanned OTT automatic weather stations operated during the 1975-76 winter in the North Water area. The Coburg Island (5 months) and Cape Hershel (1 month) stations were reoccupied to collect further data on climate, sea ice distribution and thickness and the mass balances of Laika and Leffert glaciers. The Carey Islands stations were removed and shipped south in August. Five stations were left to operate during the 1976-77 winter. Data from the six major stations for 1972-76 are completely analysed.

Isotopic Analysis of Accumulation Rates - 12 m ice cores were taken at 3 locations on Ellesmere Island and one on the Greenland Ice Cap. They were studied in the field using classical stratigraphical methods and the a.c. electrical conductivity measured. Melted samples were delivered to the University of Bern (H. Oeschger) for $^{18}O/^{16}O$ analysis and to the University of Innsbruck (W. Amback) for total β activity analysis.

Coburg Island glaciers - The long-term mass balance study of Laika Glacier, begun in 1973, was continued. Mass balance data are available for 3 years for the glacier and for the Laika Ice Cap for two years, 1974/75-1975/76. Englacial temperatures were measured on a longitudinal profile using thermistor strings installed in 1975. The surface velocity was surveyed at the narrowest part of the glacier.

White Glacier, Axel Heiberg Island - Deep drilling using an open system hot-water drill reached the bed at a depth of 160 m in the tongue area (270 m a.s.l.) and at 200 m higher upglacier (360 m a.s.l.); a third hole at 340 m a.s.l. had to be discontinued at a depth of 150 m. Cables with thermistors at 15 m intervals were frozen in. It is planned to drill 3 further sites in the accumulation area.

Mass balance observations were made throughout the summer and the stake network resurveyed. All data since 1960 is being compiled for publication in 1977.

The automatic weather stations at Moraine Profile and Point Alec were serviced, extensive repairs being required to the latter.

The tongues of Thompson, White and Crusoe glaciers were resurveyed.

Baby Glacier, Axel Heiberg Island - An intensive mass balance study was carried out during 1976. Analysis of this data and compilation of data from previous years will form the basis of a Master's thesis (Diplomarbeit).

8. University of Minnesota, Minneapolis, U.S.A.

(a) Department of Geology and Geophysics (R. LeB. Hooke)

Barnes Ice Cap, Baffin Island - Three holes were completed along the Trilateration Net flow line. That at the equilibrium line reached 161 m, one 2 km upglacier from there 223 m and the third, 1 km downglacier from the first 98 m; about 10, 20 and 40 m respectively from the bed according to sounding data.

The 98 m hole, designed for temperature studies alone, showed -8.7°C at the bottom and a nearly constant .0201°C/m gradient over the lowest 65 m.

The other two were designed for fabric, temperature and deformation measurements, but due to casing failure in the 161 m hole only fabric data was obtained there. The ice near the top of both is fine-grained (3-5 mm) with random fabric. With increasing depth grain size increased to 1-2 cm and a diffuse single-maximum fabric with c-axes generally vertical develops. Below about 110 m this splits into two maxima roughly at right angles to the direction of shear. Below 170 m a weak third maximum appears in the deepest hole. Both holes bottom in bubbly white ice of Pleistocene age which is fine-grained (3-5 mm) with a single maximum fabric. Preliminary temperature measurements in the 223 m hole indicate a basal temperature about -6.2°C and a basal gradient of about .02°C/m.

9. Canadian Exploration Group, Peterborough, Ontario

Mt. Sir Sandford Area, B.C. (J.S. Marsh) - Work on the glaciers and microclimate in the Mt. Sir Sandford area of the Selkirk Mts. was continued. The snouts of the Haworth, Silvertip and Sir Sandford glaciers were surveyed and a baseline and survey cairns established for future studies. A map at a scale of 1:5,000 is being prepared and the glacier snout positions in 1912, 1949, 1966 and 1975 have been plotted from aerial photographs. Mesoclimatic variations and glacier winds in the upper valley of Palmer Creek were studied. The 1975 results will be published shortly.

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X MATHEMATICAL GEOPHYSICS IN CANADA

Compiled by: E. Nyland

Mathematical Geophysics remains in Canada very closely linked to other geophysical subsections. The purpose of this report is to summarise, in a cursory way, the activity and to guide those interested to other sections of this bulletin. Almost all the work is research requiring large computers. This limits the activity in Canada to major universities.

In Newfoundland the group with M.G. Rochester at Memorial University continues with studies related to global dynamics. Some recent publications follow this report. C.H. Chapman and colleagues at the University of Toronto continue work on seismic wave propagation.

Recently several methods have been developed for the computation of theoretical seismograms in vertically inhomogeneous media: generalized ray theory, quantized ray theory, asympototic ray thoery, reflectivity method, spectral method, equal-phase method, etc. Each technique has its own advantages and disadvantages, depends on different approximations, varies in efficiency and has its own proponents. All suffer from the disadvantage that their use in interpretation is by trial-and-error. C.H. Chapman has studied approximations made in the various methods and has improved the theoretical techniques so that fewer of these approximations are necessary. He has developed a new method of evaluating the frequency-wave number integrals. Advantages of this new method are that it is easy and efficient to evaluate, intermediate results are stable and simple, and it contains the other methods as special cases. S.K. Dey-Sarkar and C.H. Chapman are developing this new method and its application to the inverse problem.

Together with D.E. Smylie (York University) and L. Mansinha (University of Western Ontario), C.H. Chapman has been investigating the representation of a source in a spherical earth. Now that a better understanding has been obtained, discrepancies in the literature have been explained.

At the University of Alberta F. Hron continues with work on synthetic seismograms, E.R. Kanasewich and colleagues are working on tau inversion and plate tectonic reconstructions. This work and others is covered under seismology.

E. Nyland and colleagues are investigating stability of geologic materials under shear heating conditions, seismic risk near artificial lakes, data retrieval problems related to the ISC data base, methods of inverting slow ground movement observations to properties of ground creep, and modelling methods for earthquake prone formations.

D.W. Oldenburg has completed an analysis of the theory of inversion for electromagnetic observations of ground conductivity. He expects to continue these analyses at the University of British Columbia next year. At UBC Garry Clarke continues with his model studies of glaciers. This research is reported in glaciology.

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