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Earth Physics Branch

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Report of Activities
of the
Earth Physics Branch
during fiscal year 1978-79

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Report of Activities of the
EARTH PHYSICS BRANCH
during fiscal year 1978-79.

K. WHITHAM, Director General

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The Earth Physics Branch is responsible for providing geophysical information (data, knowledge and expertise) on the configuration, structure, evolution and dynamical processes of the solid earth and the hazards associated with natural and induced geophysical phenomena, with special reference to the Canadian land mass. This responsibility has been translated into four principal missions:

- To maintain and augment geophysical data bases with appropriate technology in the fields of seismology, geothermics, geomagnetism, gravity and geodynamics;
- To provide new concepts and understanding of the basic geophysical framework of Canada for the wise utilization of the Canadian land mass and its resources;
- To assess geological hazards in Canada including earthquakes and permafrost and to contribute to the understanding of current earth dynamics phenomena such as sea floor spreading, vertical crustal motion, rotation and axial wobble of the earth;
- To apply Branch expertise and knowledge to the solution of specific national problems: thus, at the present time the geothermal group is engaged in providing a national focus for geothermal resource estimation in Canada within EMR, another group in the seismological service is providing an extensive consultatory service to the Dept. of External Affairs in the detection and identification of underground nuclear explosions, another group is engaged in permafrost studies on potential northern pipe-line routes, and all services of the Branch are contributing to the definition and implementation of a geophysical program to help validate the concept of radioactive waste storage and/or disposal in geological formations.

In carrying out its objectives, the Branch operates networks of seismological, earth motion and magnetic observatories; conducts field surveys to improve and complete chart coverage of the magnetic and gravity fields, to map the country's geothermal regime including permafrost, and to obtain paleomagnetic and seismological data for particular regions or areas of activity; and initiates prediction research related to geophysical phenomena. Since many of the geophysical phenomena studied are global in character, the Branch participates in geoscience data exchanges in the relevant disciplines, actively cooperates with World Data Centres and is the Canadian member of the International Seismological Centre.

The work is carried out by three scientific divisions, supported by an administration division which provides central administrative and technical support services such as budgeting, accounting, record and property management, stores, drafting, photography, library, carpentry and machine shop facilities. The three scientific divisions conduct their studies under five Sub-Activities: The Seismological, Geothermal, Geomagnetic, Gravity and Geodynamics Services of Canada.

The scientific program is conducted from the Ottawa Headquarters of the Earth Physics Branch and from the Pacific Geoscience Centre at the Institute of Ocean Sciences, Patricia Bay, near Sidney, B.C. At the end of March, 1979, 18 Earth Physics employees were stationed at PGC, approximately 11% of Branch strength; further transfers are predicted over the next few years as research on Western Canadian problems is decentralized so far as is possible. In 1978-79, EPB expenditures amounted to \$8.07 million, with an additional \$470K

being supplied by OERD and MOT for Energy R&D. Personnel allocation was 170 person-years.

At the end of the period under review, the main field and satellite camps for the Lomonosov Ridge Experiment (LOREX) were being established near the north pole by Branch personnel in cooperation with the Polar Continental Shelf Project. This major Canadian multi-disciplinary project of Arctic ocean exploration, designed and coordinated by the EPB, was attracting a great deal of public attention.

DIVISION OF SEISMOLOGY AND GEOTHERMAL STUDIES

M.J. Berry, Director

The Division of Seismology and Geothermal Studies is responsible for carrying out a range of seismological and geothermal activities throughout Canada through two services. The Seismological Service monitors seismic ground motion in Canada by operating a number of seismograph networks and arrays. Data from the various stations are used to determine Canadian seismicity and to estimate seismic risk, particularly in areas around urban centres and regions of industrial development located in zones that are earthquake prone. These data also provide information on the structure of the Canadian landmass and the nature of the earth's mantle and core. Extensive theoretical studies and special field experiments are undertaken to supplement the records from seismic observatories. The Geothermal Service conducts research into the thermal regime of the earth in all parts of Canada. This research is applied in three main directions: the distribution and character of permafrost are examined in order to provide information appropriate to the needs of resource industries and regulatory agencies; geothermal energy resources in Canada are evaluated to assist in research, development and demonstration related to renewable energy resources; and tectonic processes are investigated to increase our understanding of crustal evolution and resource emplacement.

The 1978-79 geophysical activities of the Branch in western Canada were carried out at the Pacific Geoscience Centre, and are reported separately in a later section.

SEISMOLOGICAL SERVICE

Monitoring of Seismic Ground Motion

The Seismological Service is responsible for the operation of seismograph stations throughout Canada, the development and calibration of seismic instruments, quality control and the collection and dissemination of seismic data. At the end of the 1978-79 review period, observations were being recorded at 19 standard and 22 regional stations. During the review period three new regional stations were installed in the southwestern Yukon as part of a cooperative project with Foothills Pipe Lines (Yukon) Ltd., and a new regional station was installed at Pinawa, Manitoba as part of a cooperative project with Atomic Energy of Canada Limited. The Eastern Canadian Telemetered Network provided telephone line or radio link transmission to Ottawa from nine outstations including Fitzroy Harbour, Ontario, in cooperation with Ontario Hydro, Manicouagan and Gentilly, Québec, in cooperation with Hydro-Québec, and three outstations near the LG2 reservoir in cooperation with La Société d'Énergie de la Baie James. The Yellowknife

seismological array continued operation and the automatic data transfer facility continued to send digital information on detected seismic events to the Ottawa computer.

Seismological Data Management

Information on approximately 30 000 P phases is reported annually by the standard stations and relayed through Ottawa to international centres for world-wide earthquake determinations. To meet the demands of national and international research institutions for original Canadian data, seismograph records are microfilmed and deposited in the files of the World Data Centres.

Specialized seismological data, from the Yellowknife array, from field projects, and from temporary special stations, are managed within the seismic data laboratory in Ottawa. The laboratory is used as the recording centre for the Eastern Canadian Telemetered Network, for special interactive research analysis and for copying and disseminating data requested by outside agencies.

The Eastern Canadian Telemetered Network recording system has an automatic detector that is triggered by, and stores digital data for, detected seismic events. Special event library tapes of both local and distant earthquakes are generated for later research analysis. During the review period hardware and software developments were undertaken to expand the capacity of this system to meet new demands associated with the siting of nuclear reactors.

Seismological Studies of Earth Dynamics

In 1978-79, the Service continued its study of Canadian earthquakes in three general time frames: rapid determination of epicentral parameters, within about 48 hours, of earthquakes of interest or concern to the general public; preparation of preliminary bi-monthly lists of earthquake activity for distribution to interested agencies; and preparation of definitive annual catalogues of earthquakes in Canada and adjacent areas. These investigations of Canadian earthquakes are based on recordings from the seismograph stations and are undertaken to delineate regions of significant earthquake activity, to assess earthquake risk, and to contribute to general geophysical studies of the tectonic forces acting within the Canadian landmass.

Service personnel responded to many inquiries from the press and the general public concerning earthquakes and other phenomena. The largest earthquake to affect Canada since the 1964 Prince William Sound, Alaska earthquake occurred in the St. Elias Mountains of southeastern Alaska on 28 February, 1979. The magnitude was 7.7 and the shock was felt widely and did minor damage in the southwestern Yukon and northwestern B.C. Service personnel are undertaking special studies of this earthquake in cooperation with personnel of the U.S. Geological Survey. Six moderate earthquakes were felt widely in British Columbia, and fourteen minor earthquakes were reported felt in eastern Canada, in the region from New Brunswick to eastern Ontario.

Special investigations of significant Canadian earthquake zones have continued. The continuing operation of an array of seven special stations in the Charlevoix region of the lower St. Lawrence has provided sufficient data to accurately outline the three-dimensional pattern of microearthquake activity. Detailed study of the 28 February, 1978 earthquake near St-Donat, Quebec has revealed that a uniform stress condition exists throughout western Quebec, and available data suggest a systematic change in earthquake depths across the active zone. A seismicity survey using portable seismographs was conducted on northern Baffin Island in September and October, 1978. Analysis of detected earthquakes is continuing in order to accurately delineate the

active zone and to correlate the seismicity with other geological and geophysical features. Analysis of data from the new southwestern Yukon stations is beginning to delineate the seismicity in relation to mapped faults in this geologically complex region. A review is underway of all available evidence for correlations between seismicity and geological, geophysical, geodetic, stress, Landsat, and other relevant data in the western Quebec - eastern Ontario earthquake zone.

The Service has continued cooperative projects with Hydro-Québec and Société d'Energie de la Baie James to monitor seismic activity in the vicinity of the Manic and La Grande 2 damsites, respectively. Three telemetering stations were installed near the La Grande 2 reservoir in October, 1978, prior to reservoir filling. Approximately 100 induced microearthquakes have been located during the reservoir filling period to the Spring of 1979. Low-level seismic monitoring is also being done in cooperative projects with Ontario Hydro and Hydro-Québec at potential sites for nuclear power stations, and with Atomic Energy of Canada Limited in the early stages of regional coverage for the radioactive waste repository program.

The Seismological Service responds to numerous requests for information on seismic risk from engineers, various government and commercial agencies and the general public. Current research is being directed toward new seismic risk maps of Canada. The recent seismicity data base is being employed with new analysis methods to derive risk maps that provide a variety of strong ground motion parameters of relevance to engineering design. Service personnel continue to be active in the Canadian National Committee on Earthquake Engineering and the Canadian Standards Association Technical Committee on Seismic Qualification of CANDU Nuclear Power Plants.

Seismological Studies of Earth Structure

The Service studies the dynamic processes, materials and structure of the earth underlying Canada, using a wide variety of techniques. All these techniques are fundamentally based upon the arrival times and amplitudes of seismic waves propagating from distant earthquakes and nuclear events or from controlled seismic sources at shorter distances. Seismic waves provide one of the few direct probes available to earth scientists as they investigate the properties of the earth from its near surface crustal layers down to its inner core.

Seismological studies of the Charlevoix region in the lower St. Lawrence valley have continued as part of a broad range of geophysical studies of this active zone. Three explosions were detonated in May, 1978, one of which served as part of a continuing refraction study. Two further calibration shots in August were part of the continuing series to monitor travel-time and velocity changes that may precede large earthquakes. In November, two shots were detonated at high and low earth tide, respectively, to test the hypothesis that the tide may cause changes in velocity. To within 2 milliseconds, no changes were observed. Seismic reflection/refraction interpretation of these shot data has revealed structural contortions in the upper crust probably resulting from the Charlevoix meteorite impact 350 million years ago.

As part of the integrated geophysical studies in the joint AECL/EMR program of research on geological disposal of radioactive waste, the Service undertook a study of the variation of compressional velocity versus azimuth and depth at the AECL Whiteshell Nuclear Research Establishment (WNRE) near Pinawa, Manitoba. Contracts were let and high-resolution seismic reflection studies performed using the Mini-Sosie technique at WNRE and at the AECL Chalk

River site. A clear and coherent reflection at about the 500 meter depth was obtained at WNRE and has been related to a major shear zone known, from drill holes, to occur within the batholith. The technique appears to be a viable tool for reconnaissance and preliminary evaluation of potential radioactive waste disposal sites.

Interpretation of seismic refraction data recorded over the Beaufort Sea during the AIDJEX project in 1976 has revealed a crust that grades from typically oceanic to intermediate as the section nears the continental slope off northern Alaska. There also appears to be crustal velocity anisotropy with the highest velocity normal to the Alaska coastline.

Geoscience of Nuclear Explosions

The Service is responsible for basic and applied research into the use of seismology; in particular, it conducts investigations and provides advice to the Department of External Affairs on all matters pertaining to seismological verification of a treaty banning underground nuclear explosions. Analysis of seismic events, predominantly underground nuclear explosions, has continued and the Yellowknife array detection bulletin continues to be made available to research groups abroad for studies of rapid detection and location of seismic events.

A Service officer continued to represent Canada in the Ad Hoc Group sponsored by the Committee on Disarmament in Geneva to consider international cooperative measures to detect and identify seismic events.

GEO THERMAL SERVICE

Geothermal Studies of the Canadian Land Mass

During 1978-79 studies of the thermal state of the Canadian landmass were concentrated in the western Cordillera, the western platform and the arctic regions. Research in all of these areas provides valuable background information for the assessment of geothermal energy potential or for studies of permafrost-induced hazard to conventional hydrocarbon production.

Measurements of radioactive heat generation were made on rocks from plutons in southern British Columbia, notably in the Grand Forks area, in an effort to locate zones of high rock temperature and to trace the extension of a known thermal anomaly zone north of the international boundary. A second set of heat flow measurements was made in the deep fjords of the west coast between 52°N and 56°N. These measurements will complement and confirm the earlier measurements, and, since they were made at a different season, they will help in the detection of any seasonal anomalies.

A study of existing data from oil and gas wells in the Prairie Provinces was started. Although industrial temperature data are of low accuracy, the very great amount of data available permits broad thermal patterns to be identified. Further possible developments of this study include determination of thermal conductivities of sedimentary rocks, analysis of lithological data, and the compilation of a heat flow map. Temperatures in potential heat producing aquifers and temperature data for well cementing operations will result from these studies.

Temperature measurements in wells in the far north of Canada have continued, bringing to over 100 the number of determinations of permafrost thickness, and to a similar number the wells in which detailed thermal profiles are available. Profile data have been used to detect the presence of gas hydrates and to test scenarios of hydrocarbon production through permafrost horizons. Detailed analysis of geothermal data was started in the

Ungava area of Northern Quebec where the complex climatic history has a profound effect on subsurface temperatures. This type of analysis will later be extended across the north to develop an improved understanding of past climatic events and to produce a regional heat flow map.

Assessment of Canadian Geothermal Energy Potential

The Geothermal Service coordinates activities of the Federal Government in the field of geothermal energy research and development. Field observations of the thermal state of the earth's crust by the Earth Physics Branch and of the age and character of volcanic zones by the Geological Survey of Canada provide basic information on which to base contracted studies aimed specifically at the recognition and assessment of geothermal resources.

During 1978 a shallow drilling programme was completed in the Coryell Syenite pluton north of Grand Forks, British Columbia. It was shown by temperature measurement that thermal gradients are anomalously high, and that potential for hot dry rock exploitation may exist in this and other similar areas. Radioactive heat generation of the drill cores was found to be high, and is to be studied further as a method of identification of potential resource areas.

At Meager Mountain, in the Garibaldi Volcanic Belt, two holes were drilled in cooperation with B.C. Hydro to test thermal conditions. One hole was placed on the north side of the mountain, close to the most recent eruptive centres. The other hole was placed on the south side, in an anomalous area, previously identified by electrical resistivity surveys. Temperatures in excess of 100°C were encountered in both holes, showing evidence of convecting hydrothermal systems. This was the first unequivocal demonstration of active hydrothermal circulation and the estimated probability of exploitable geothermal energy being present was greatly enhanced. Plans for further work to exploit this success were formulated during the winter.

A well was drilled on the Campus of the University of Regina as the final step in the confirmation of geothermal resources in the lowest sedimentary formations. The total depth of the well was 2 214 m and potentially producing formations were encountered from 2 029 m to 2 209 m. Tests indicated good porosity and permeability and a good potential rate of water supply. The temperature of the water is expected to be about 70°C. The well is regarded as a successful confirmation of predictions and as an indication that a successful geothermal heating demonstration project can be completed on the site. Further tests and data collection are planned.

Applied Permafrost Research

Under the Energy Research and Development programme a small project was initiated to conduct permafrost research related to frontier hydrocarbon exploration, production and transportation. In 1978/79 several contracts were supported to investigate water migration phenomena in frozen soils by studying such physical characteristics as soil permeability, unfrozen water content, isotope redistribution, and thermal properties. In addition, an arctic lake was drained after a preliminary geophysical and geological survey and the development of permafrost and permafrost-related phenomena, such as ice-lens growth and lake bottom heave, are being monitored in the previously unfrozen sediments.

During the Spring of 1978, 12 holes were drilled hydraulically from the sea-ice of the Beaufort Sea to maximum depths of 61 m. The holes located across the Delta Front north of Richards Island were instrumented with temperature cables. Much of the sea-bottom material encountered was

marginally ice-bonded at temperatures averaging from -1.5 to -1.0°C , exhibiting isothermal conditions indicative of relict degradational permafrost conditions.

Increased funding from the Energy R & D programme in 1979/80 will allow a small expansion in gas hydrate research, in particular its physical characteristics and detection in the subsurface.

The establishment of a joint Industry/Government Working Group on problems of northern hydrocarbon development late in 1978 formalized previous ad-hoc arrangements. This should help to identify serious remaining deficiencies in permafrost research.

PACIFIC GEOSCIENCE CENTRE
W.G. Milne, Chief Scientist

His Excellency Edward Schreyer, Governor General of Canada, officially opened the Institute of Ocean Sciences including the Pacific Geoscience Centre on February 28, 1979. By then, most of the problems associated with the joint operation of the new facility had been resolved. The programs, which are outlined below, are components of national geophysics programs, and frequently constitute joint studies by the Earth Physics Branch and the Geological Survey of Canada. The Institute of Ocean Sciences of the Department of Fisheries and Environment is the lead agency at the site, and operates the common library, shops, stores and computer facilities. The ships which are used on the EMR programs are also operated by the Institute as part of an agreed program. During the review period, three staff members, in seismology, geomagnetism, and geodynamics were transferred from Ottawa to P.G.C.

SEISMOLOGICAL SERVICE

Monitoring of Seismic Ground Motion

The 4 station Western Canadian Telemetered Network (WCTN) has operated from the Pacific Geoscience Centre (PGC) without significant interruption during the review period. The short and long period three components of the PGC standard seismic station operate, with WCTN and other recording facilities, within a room which is open to view for the tours conducted by the Institute. Considerable public interest in this program has subsequently developed. The basic network of 98 strong motion seismographs deployed along the west coast and lower mainland remained in operation with the servicing of most of the instruments being carried out under contract. A stand-by accelerometer was rushed to a site in southwestern Yukon following the large earthquake on February 28, 1979.

Seismological Data Management

Information on the significant phases and related intensity reports are forwarded by teletype to Ottawa for local and teleseismic events. Programs on the Institute computer now routinely determine epicentres for regional earthquakes. Data from the tape file of Canadian earthquakes have been supplied, on a cost recovery basis, to other research groups or to firms engaged in the earthquake resistant design of structures.

Seismological Studies of Earth Dynamics

Residents of Vancouver Island report feeling several earthquakes each year, some with epicentres in Canada, but others such as that on December 31st

with epicentres in Puget Sound, U.S.A. During the review period the following moderate earthquakes in Canada were felt: May 14, 1978 near Valemount in the interior (Magnitude (M) =4.7); June 2, 1978 near Brooks Peninsula, Vancouver Island (M=5.7); July 11, 1978 west of the Queen Charlotte Islands (M=5.1); July 25, 1978 again near Brooks Peninsula, Vancouver Island (M=5.6); and August 19, 1978 west of Victoria (M=3.5). Intensity studies have been made within the epicentral regions of these earthquakes, and although no serious damage has been reported indications are that the Brooks Peninsula events did a moderate amount of damage near Port Alice. The Brooks Peninsula earthquakes were accompanied by a series of aftershocks, some of which were studied during a special field survey.

Information was supplied to engineers concerning earthquake risk for specific sites or structures in the region according to the methods developed for the National Building Code. As part of a continuing program to develop this methodology, a study was started to define the active earthquake source areas along the coast.

Seismological Studies of Earth Structure

Data obtained during the 1977 marine field program were analyzed at UBC under an EPB contract. Seismic profiles in the regions of the Winona Basin and the triple point are now being prepared, and compared with synthetic seismograms from representative crustal models. The deep structure of the crust and upper mantle of eastern North America was studied during the period by comparing real with theoretical seismograms calculated for realistic earth models.

GEOHERMAL SERVICE

Delineation of the Geothermal Regime

In the Spring scientists from Ottawa and the PGC combined to measure heat flow and to sample the bottom sediments in the fjords along the coast of British Columbia. The measurements of heat flow were part of a more regional study of the distribution of heat flow across the coastal margin. In the Summer, heat flow measurements were made in the Winona Basin and in the Autumn another short cruise was undertaken to Pitt Lake, east of Vancouver, where further geothermal data were collected. The collection of geothermal data during the past few years has confirmed the existence of hydrothermal convection cells with horizontal dimensions ranging from one to tens of kilometres. The effect of these cells is superimposed on the regional heat flow determined by the offshore spreading ridges and subduction of the oceanic plate beneath Vancouver Island. The effect of the cells is to make the geothermal regime less systematic than had been postulated.

GEOMAGNETIC SERVICE

Magnetic Observatories

During the reporting period, the Victoria Magnetic Observatory continued to operate at the Dominion Astrophysical Observatory site, using the Automatic Magnetic Observatory System (AMOS) as the primary recorder with a long-playing photographic system as a back-up. A recording system has also been installed at PGC to supply data to contractors who require an instant evaluation of the level of geomagnetic activity. This recording unit is on public display.

Management of Geomagnetic Data Base

Baseline corrections for Victoria Magnetic Observatory were derived from absolute measurements, and one-minute digital values were processed for transmission to World Data Centres, with microfilmed magnetograms, on a monthly basis. Indices of magnetic activity were determined and sent to international agencies twice a month.

Geomagnetic Studies of Earth Structure

Ocean-bottom magnetometers recorded magnetic variations in three components for a ten-day period in the vicinity of the Juan de Fuca spreading ridge. The experiment indicates that the layer of high electrical conductivity associated with this active spreading ridge is not narrow but in the form of a broad band centred on the crest of the ridge.

Data from the ocean-bottom magnetometers and from recording stations on land have been used in an evaluation of techniques for correcting marine total-intensity surveys for time-dependent variations. By examining the discrepancies observed at intersections of survey lines whose locations are known precisely by Loran-C, it was concluded that a recording base station some distance inland provides statistically better corrections than one on the coast and closer to the survey. The most reliable corrections were derived by combining the vertical component variations recorded by the ocean-bottom magnetometers with horizontal components from land stations not too close to the shore.

GRAVITY SERVICE

Gravity Mapping

During the review period the IOS ship Parizeau was used for an eight week multiparameter survey west of the Queen Charlotte Islands, and in Dixon Entrance to the north. The data collected during the cruise included bathymetric, geomagnetic, gravity, and some seismic profiles from survey lines spaced 5 to 7 kms apart. These data are currently being studied, and the first indication is that the Queen Charlotte transform fault, which can be reached at the eastward end of these lines, is a broad feature with at least two possible rift valleys.

Gravity Studies of Earth Structure

The gravity and structure of the margin of the Juan de Fuca and Explorer plates have been analysed in terms of the oblique convergence of these plates with North America. Gravity profiles across Vancouver Island provide evidence for slow, active subduction of the Juan de Fuca plate, though there is no known seismicity specifically associated with underthrusting. Further north a complex system of sub-plates has been delineated and their motions analysed to provide some understanding of the seismic source zones in the region.

GEODYNAMICS SERVICE

Dynamics of the Earth

Semi-annual gravity surveys of a precise gravity network on Vancouver Island were continued in 1978/79 by contract to private industry. The tectonic implications of some significant trends in the network data are not yet understood. A contract program with UBC scientists has provided data to show that in the region of the severe earthquake in 1946, there is evidence for about 1 meter of horizontal movement of a right lateral nature with the probability of accompanying vertical motion.

A nanogravity meter test range has been established at PGC for the purpose of instrument calibration and the observation of short term changes in gravity. Exploratory measurements of the tilt and gravity tide, carried out in the Geodynamics vault in preparation for the installation of more sensitive instruments, have been recorded in the display room for the interested public.

DIVISION OF GEOMAGNETISM

P.H. Serson, Director

The Division of Geomagnetism is responsible for providing up-to-date information on the magnetic field of the earth to users in many areas, including navigation, telecommunications, and geophysical exploration. The Geomagnetic Service responds to over 2 000 requests per year for values of the magnetic declination and its secular variation, for use in maps and manuals published by other federal, provincial and international organizations. Every five years, the Service publishes revised magnetic charts of Canada and the adjacent ocean areas. In addition, data are provided, in analogue and digital form, on the daily variation of the magnetic field and on magnetic storms; and regular forecasts of magnetic activity are issued, by mail and by telephone.

The Geomagnetic Service maintains the data base necessary to carry out its various functions by conducting systematic surveys, on the ground and in the air, and by operating the Canadian Magnetic Observatory Network. The Network consists of 11 fixed observatories, which continuously record the intensity and direction of the varying magnetic field.

The Division's research program includes paleomagnetism, interpretation of aeromagnetic anomalies, electromagnetic induction in the earth, and studies of geomagnetic time variations and pulsations. Canada provides a particularly favourable environment for research on these aspects of geomagnetism. Its landmass contains the north magnetic pole and is bisected by the auroral zone. It is the only major landmass in the world in which magnetic disturbances and related upper atmospheric phenomena are accessible for study from polar regions to subauroral latitudes. Large anomalies in electromagnetic induction indicative of highly conducting zones in the crust or upper mantle are found in the Arctic Islands and in the Cordillera. Canadian geological history, extending from Archean time to the present, provides an opportunity for studies of paleomagnetism and continental evolution over a time span exceeding two billion years.

Other work of the Division includes the use of magnetic and magnetotelluric methods to study and locate geothermal resources in Western Canada. The usefulness of these techniques for earthquake prediction is being assessed in a seismically active region on the north shore of the St. Lawrence.

GEOMAGNETIC SERVICE

Magnetic Observatories

The 11 magnetic observatories that operated throughout 1978-79 were located at Mould Bay, Resolute Bay, Cambridge Bay, and Baker Lake in the Arctic; at Yellowknife, Churchill, and Great Whale River in the auroral zone; and at Victoria, Meanook, Ottawa and St. John's in southern regions. Continuous recordings of magnetic field variations, with limited control of absolute levels, were made at the variation stations at Whiteshell, Manitoba, and at Alert, on Ellesmere Island.

At all the above stations except Mould Bay and Alert, the Automatic Magnetic Observatory System (AMOS), developed by the Division of Geomagnetism, records the northward, eastward and vertically downward components of the magnetic field, and its total intensity, once per minute in digital form on magnetic tape. The tapes are sent to Ottawa at the end of the month for editing by computer. The operation of the AMOS installations is checked daily by telephone from Ottawa.

The prototype of a new Automatic Magnetic Observatory System (AMOS Mk III) was constructed and tested in the Ottawa laboratory. It is controlled by a microprocessor, and in addition to the functions performed by the original AMOS, it carries out various tests on the data being recorded, and will store diagnostic messages, mean hourly values, ranges and a limited amount of one-minute data for interrogation from the control centre by telephone.

A contract was awarded to EDA Instruments Inc. under the federal COPI program to develop a production version of AMOS Mk III for the international market. The contract, to be completed in late 1979, calls for the preparation of diagnostic routines for servicing the instrument as well as complete hardware and software documentation packages.

International Magnetospheric Study (IMS)

The Geomagnetic Service continued to operate by contract 9 magnetic variation stations as part of the program of the International Magnetospheric Study (IMS). Together with some of the standard magnetic observatories these stations complete a crossed array in the auroral zone, centred on Churchill, Manitoba. The meridian stations are Whiteshell, Island Lake, Gillam, Back, Fort Churchill, Eskimo Point, Rankin Inlet, Baker Lake, Pelly Bay, Resolute and Alert. The east-west line consists of Great Whale River, Fort Severn, Gillam and Thompson. All stations record three magnetic components on digital magnetic tape, and most have analog recorders as well. Six of the stations are equipped with a telemetering system provided by US agencies, which transmits the magnetic data to Boulder, Colorado, via geostationary weather satellites.

Magnetic Surveys

In a continuing study of the magnetic secular variation, 18 magnetic repeat stations in the Northwest Territories were occupied by contract during April, May and June. In the Fall 4 additional stations in British Columbia were occupied. At each repeat station a three-component digitally-recording magnetometer was operated for at least 30 hours, while absolute measurements of declination, inclination and total intensity were carried out to provide absolute control of the recordings.

A proton-precession magnetometer was installed on the CCGS Narwhal for the last phase of a four-year multi-disciplinary survey of Hudson Bay. Approximately 20 000 km of total intensity profiles were obtained, with the magnetometer sensor towed 110 m behind the ship. Because the auroral zone crosses the survey area, disturbance fields present major problems in the data reduction. A correction technique has been developed and has been applied to data from the first three years of the Hudson Bay survey project.

Management of Geomagnetic Data Base

Observatory Data

Microfilm copies of magnetograms from the 11 magnetic observatories plus Alert and Whiteshell were deposited monthly in World Data Center A, Boulder,

Colorado, from where copies go to all other world data centers. Final digital tapes for 1977 from all AMOS stations and preliminary 1978 tapes for most stations were sent to World Data Center A, and to geophysical exploration companies on request. The annual report on magnetic observatories for 1976 was sent to publication.

IMS Data

Tapes containing edited one-minute values for the variation stations of the Churchill array, from September-October 1976 (when digital recording was installed) until the middle of 1978, have been deposited in World Data Center A. Priority is now being given to processing data from the Fort Severn, Thompson and Mould Bay stations, which are not provided with satellite telemetry equipment.

Forecasts of Geomagnetic Activity

As a service to the geophysical exploration industry, electric power utilities and oil and gas pipeline companies, the Ottawa Magnetic Observatory issues two types of forecasts of the level of geomagnetic activity. A 27-day forecast prepared at three-week intervals is distributed by mail to a list of customers which now exceeds one hundred, and a three-day forecast prepared twice a week is available by telephone. A system for distributing the three-day forecast by telex which was tried during the 1978 survey season received little use, because the field parties rarely had access to telex equipment. In 1979 it will be replaced by an automatic telephone answering device which operates 24 hours a day.

Magnetic Charts

Recent secular change measurements show that over much of Canada the magnitude of the annual change in declination has at least doubled since 1970. For example, near Edmonton the annual change has increased from 3' west in 1970 to 13' west in 1978. While the horizontal component is still increasing over most of the country, with a maximum of 70 to 75 nT per year in the southeast, the increase appears to be slowing in Alberta and British Columbia. The large decrease in the vertical component and total intensity, noted in the 1977 report, is rapidly extending northward. The decrease at Ottawa now exceeds 100 nT per year, and Fort Churchill shows a decrease of 30 nT per year. The 1978 measurements in the western Arctic Islands indicate that the centre of decrease has spread to that region.

Paleomagnetic Data

Much effort is being devoted to constructing apparent polar wandering (APW) paths and to associated problems. Papers have been published discussing the methodology of the reconstruction of Precambrian APW, a new APW path for Gondwana, and the statistical deficiency in the number of high-latitude Precambrian poles observed. Numerous paleopoles from the Western Cordillera show that certain terrains, now embedded in the Cordillera, were once displaced relative to "stable" North America by thousands of kilometers in the Mesozoic and Tertiary. Recent studies in Siluro-Devonian rocks in the Appalachians have yielded paleopoles up to 60° away from poles of comparable age from "stable" North America, and the question arises, do these poles represent displaced terrain like those found in the Cordillera?

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

Geomagnetic Studies Of Earth Structure

Paleomagnetism

Recent Precambrian studies from the Coronation Geosyncline have been published, or are in press. In or near the Grenville Province, papers on the Charlevoix anorthosite and the Seal Group have been submitted for publication, and experimental work on the Larrimac and Bryson diorites continues. A paper has been published on the Jacobsville Formation. Work continues under contract on the Sudbury Irruptive. For the Appalachians, papers on the Botwood Formation and Mt. Peyton intrusives of Newfoundland, and on the Mascarene Formation and St. George and St. Stephen's intrusions of New Brunswick are in press.

New procedures for data listing and graphics designed to automate the study of multicomponent magnetization are now in place. A paper discussing the impact that such studies have on paleomagnetic interpretations has been published.

Electromagnetic Induction in the Earth

Data from 3-component recording magnetometers at six sites in the central Arctic imply the existence of two broadly different crustal regimes in the Queen Elizabeth Islands. There is evidence for a layer of high electrical conductivity about 10 km deep beneath Ellef Ringnes, Melville and Banks Islands and further west, while no such layer is present east of these islands.

As a contribution to the EPB program to study earthquake precursors, recording of magnetotelluric fields has continued at 4 sites in Charlevoix County near La Malbaie. A paper on this work has been published and an open file report has been prepared on a local zone of very high electrical conductivity which was discovered near the village of Ste. Mathilde.

Observatory data from St. John's, Ottawa, Agincourt, Newport and Victoria have been examined for five magnetically quiet days. The enhanced vertical components at St. John's and Victoria demonstrate a long-period coast effect similar to that observed in Australia and California. Also, the daily variation of the vertical component has a much smaller amplitude at Ottawa and Agincourt than at Newport. This may indicate internal electrical conductivity higher to the east and lower to the west, the reverse of many currently accepted models.

A study on the usefulness of electrical resistivity sounding as a technique for detecting crustal dilatancy prior to the onset of an earthquake has been published.

Data from a magnetovariation and magnetotelluric station on the sea ice of Viscount Melville Sound in the Western Canadian Arctic obtained during April 1978 have been analysed, along with simultaneous magnetic variation data from Resolute, 300 km to the east. One-dimensional modelling of the geomagnetic response suggests that an upper mantle conductor (conductance of the order of 10^5 S) underlies both sites, with its top surface at a depth of 70-100 km.

Magnetic Anomalies

An investigation of very long wavelength lithospheric magnetic anomalies over Canada has been made, using upward continuation and polynomial techniques developed for this purpose. Correlations between the regional magnetic anomalies in the 300-3000 km waveband and shorter wavelength anomaly signatures have been observed. However, at least one broad anomaly appears to be caused by a correspondingly large source region of high magnetization. An

upward continuation to 300 km altitude over western Canada gives an estimate of the anomaly field to be expected at MAGSAT orbital altitudes.

Lithospheric magnetic anomaly data from the Ogo 2, 4, and 6 (Pogo) satellites have been compared with upward continued airborne magnetometer data between 50°-85°N and 100°-140°W, at a mean altitude of about 500 km, in a joint project with NASA personnel. Agreement is good both in anomaly location and in amplitude, giving confidence in the validity of the satellite data. Major differences in the regional magnetizations of various parts of the western North American craton are apparent. A striking feature is the magnetic high over the Alpha Ridge in the Arctic Ocean which is interpreted to indicate that the Ridge is of continental composition.

Geomagnetic Disturbances

Magnetic Storm Analysis

A statistical analysis of magnetic substorms occurring in the cleft region north of Cambridge Bay showed that such high-latitude observatories should be included in the determination of the AE (auroral-electrojet) index. The simultaneous occurrence of eastward and westward auroral electrojets during daylight hours was clearly demonstrated by an investigation of substorms following the solar flares of September 16-19, 1977.

Pederson and Hall electric currents in the ionosphere were determined from plasma and electric field observations made by a rocket over Greenland, and were compared with electric current calculated from total magnetic field measurements made by the same rocket. A similar method was used to investigate currents flowing in the Harang discontinuity over northern Sweden.

Magnetic Pulsations

A study of pulsations with periods 150 to 600 seconds recorded along 67°N latitude indicates that the source of the morning activity is localized at the dawn meridian, while the longitudinal variation of phase suggests the propagation of signals away from noon toward the dawn-dusk meridian. The sense of polarization in the horizontal plane reverses as the station crosses the noon meridian; polarization in the vertical plane appears to be controlled by internal induction, at least in eastern Canada.

Solar and Lunar Variations

Hourly mean values of the magnetic elements have been analysed by the Chapman-Miller Method to obtain the solar and lunar harmonic coefficients, for Meanook (1932-1976), Agincourt (1932-1966) and Nurmijarvi (1952-1973).

GRAVITY AND GEODYNAMICS DIVISION

J.G. Tanner, Director

The Gravity and Geodynamics Division is responsible for operating the Gravity Service and the Geodynamics Service of Canada. The Gravity Service maintains and augments annually the National Gravity Data Base, maintains national gravity standards, publishes gravity maps and reports, and provides gravity and related information to users in the public and private sectors, both nationally and internationally. The data base is also used for in-house geodetic studies and studies that contribute to an understanding of local geologic features and regional geological frameworks in Canada. The

Geodynamics Service is responsible for studies of the Earth's rotation, polar motion and earth tides, and for investigations of crustal strain and tilt related to tectonic movements, groundwater levels, and earthquake prediction.

GRAVITY SERVICE

Gravity Mapping

During 1978-79 36 000 line kilometers of shipborne gravity profiling were completed and more than 5 100 new static gravity stations were established over the Canadian mainland and offshore areas. The shipborne surveys were carried out in cooperation with the Canadian Hydrographic Service, Department of Fisheries and Oceans, and were highlighted by surveys west of the Queen Charlotte Islands, where track spacing varied from 6 to 10 km, and in Hudson Bay which saw the completion of a planned four-year program of dynamic gravimeter measurements in the area. Overall, track spacing in the latter region is less than 10 km. In February and March, 1978, another cooperative survey with CHS completed 1 200 gravity stations at 6 km intervals on the frozen surface of Hudson Bay, north and east of the Belcher Islands. In the Northwest Territories a helicopter-supported party observed about 1 200 stations in the eastern half of Viscount Melville Sound. This survey, supported by the Polar Continental Shelf Project, was also carried out in cooperation with the CHS.

In British Columbia approximately 300 new gravity stations were observed in the Rocky Mountains as a result of the first year of a three-year contract and where, for the first time, a helicopter-mounted inertial survey system was used to determine the latitude, longitude and elevation of gravity observation points.

In support of a requirement for the Geodetic Survey of Canada, Surveys and Mapping Branch, more than 1 400 gravity observations, at a spacing varying from 1 to 3 km, were made via contract to industry at precise level bench marks and associated precise elevation points along the Alaska Highway between Fort Nelson, B.C. and the Alaska-Yukon Boundary. A contracted survey of Lake Winnipeg using helicopter transportation during February and March 1978 completed nearly 700 gravity observations at 6 km intervals throughout the length of the lake. During August, a car-supported survey completed the 6 km regional gravity coverage of southwestern Nova Scotia.

Investigations in dynamic gravimetry have centered around the evaluation of the LaCoste and Romberg air/sea gravimeter as an inertial survey system (ISS) to provide simultaneous observations of horizontal position, elevation and gravity. Two series of tests were carried out in the past year and final results indicate that accuracies of 20 m in horizontal position, 1.3 m in elevation and 0.2 mgal ($1 \text{ mgal} = 10^{-5} \text{ m/s}^2$) in gravity can be achieved when the gravimeter is operated in the ISS mode.

Six new open files and one new map in the gravity map series were released during the year.

Gravity Standards and Gravity Data Base

The systematic inspection and updating of control stations of the National Gravity Net continued under contract in Northern Alberta, British Columbia and the Yukon Territory. A total of 47 old stations were recovered and 95 new stations were established. Gravity values and descriptions for these stations are now available upon request.

The gravity anomaly file was brought into production under System 2000 (S2K) and great improvements in the speed and ease of retrieval have been

experienced. A new plotter (Calcomp 960) was obtained and due to the on-line capability of the machine, plot production has increased noticeably.

The National Gravity Data Base incorporates gravity and related data obtained by departmental surveys or contributed by external agencies. In response to 92 requests received during the past year from government agencies, exploration companies and universities, the Gravity Data Centre retrieved and distributed 50 million characters of information, mostly in the form of magnetic tapes. Approximately 20% of the requests required preparation of digital anomaly maps. Also, 440 descriptions of reference stations were requested. In support of in-house field and research programs, an additional 139 requests were processed involving the retrieval of 2 million characters of information, most of which were produced in plotted form.

Gravity Studies of Earth Structure

Studies of gravity anomalies and other related geophysical data provide information on the deep structure of the lithosphere and asthenosphere. Such information provides an added dimension to geological and resource frameworks as well as adding to our knowledge of geological processes and earth structure.

A branch-wide study of Arctic geophysical data has been published. This new volume first reviews the history of geophysical measurements in the Arctic, then reconstructs the development of the Arctic Basin using these measurements and major tectonic relationships as constraints. Chapters on bathymetry, gravity and evolution of the Arctic Basin were contributed by the Division. Included with the volume are 1:7 500 000 maps of bathymetry, observed/predicted free-air gravity and residual free-air gravity north of 60°N.

Also in the Arctic, two detailed gravity profiles along the axis and across the northwestern margin of the Sverdrup Basin have been analysed in conjunction with deep and shallow seismic refraction data obtained by the department in 1972, 1973 and 1974. Preliminary results indicate that long wavelength anomalies correlate well with variations in lithology and thickness of the basin fill and variations in crustal thickness.

Structural models of the coal-bearing Bonnet Plume Basin in the Yukon Territory were determined along a profile transecting the basin. The gravity and density relationships indicate an eastward gently dipping basin containing Tertiary-Cretaceous clastic sediments which attain a maximum thickness of between 0.8 and 4.7 km. More accurate estimates of thickness could not be made due to an inadequate knowledge of the subsurface distribution of upper (lower density) and lower (high density) members of the succession. Application of a two layer model for the Bonnet Plume Formation indicates that the upper lignite-bearing member may be more restricted in occurrence than previously thought and that most of the basin south of the profile is underlain by the lower member containing sub-bituminous coals.

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

A large positive gravity anomaly with an amplitude of over 60 mgal coincides with the eastern part of the Lac Fournier Anorthosite Massif located

about 200 km northeast of Sept Iles in the Grenville Province, Quebec. A more mafic-rich phase of anorthosite than found elsewhere in the complex is present in the anomalous region and, with the evidence of the gravity data, is interpreted to represent the upper levels of a differentiated magma body. The body, interpreted to be gabbroic in composition, was modelled in three dimensions.

An interpretation of the gravity field over the circular depression within Skeleton Lake, Ontario, has been completed. Taken in conjunction with aeromagnetic and geological data, the anomaly was interpreted as due to a partly eroded impact crater of Paleozoic age with a diameter of 3.6 km. A gravity survey was conducted at the Triassic Lake St. Martin structure near Gypsumville, Manitoba. Preliminary analysis of the data indicates a distinct negative anomaly over the 24 km diameter circular structure which, on the basis of earlier studies of shock metamorphism, has been attributed to hypervelocity impact.

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

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

Field studies continuing Branch investigations of crustal melting and rock magnetisation by intense shock pressures were conducted at the Lake St. Martin structure, Manitoba, and, as part of a joint Australia/U.S./Canada expedition, at the Strangways crater, Northern Territory, Australia. Joint studies with the Max-Planck Institute, Mainz, into the composition of bodies which formed large craters and with the University of Toronto on the dating of impact events continued. A new analysis of impact rates over geologically recorded time was completed and shown to compare closely with lunar cratering rates and the present day flux of earth-crossing asteroids.

Radioactive Waste Disposal Program

An expanded program of geophysical surveys and laboratory measurements, many carried out by contract, was conducted in collaboration with other branches as part of the Department's contribution to the radioactive waste disposal program. Seismic, gravity and magnetotelluric surveys were made on selected profiles in the AECL test areas of Chalk River, Ontario and Pinawa, Manitoba. Drill holes at both sites were logged geophysically and used to investigate regional aquifer characteristics by monitoring the response of water levels to earth tides and other strains. Laboratory investigations of rock magnetic, elastic, thermal and petrofabric properties were conducted to determine mineral and crack characteristics as a basis for evaluating rock integrity from regional and detailed surveys. Plans have been drawn up to extend these studies to other research areas as part of the concept evaluation

phase of the program. The Division continues to coordinate all EMR geophysical work in this program.

GEODYNAMICS SERVICE

The Generation and Management of Geodynamic Data

Earth's rotation, polar motion and crustal plate dynamics continued to be monitored by satellite doppler and optical astronomical (PZT) observations from two polar motion observatories which are located near Ottawa, Ontario, and Calgary, Alberta.

The doppler observations of navigational and geophysical satellites are carried out by two computer controlled TRANET stations. Their operation has been fully automated by means of a mini-computer distributed network which facilitates unattended data acquisition, processing and real-time communication to the DMAHTC Satellite Polar Monitoring Center in Washington, D.C.

The nightly operation of the PZT instrumentation is also automated; photographic plates are evaluated daily and the results are transmitted weekly to the Bureau International de l'Heure (BIH) in Paris and monthly to the International Polar Motion Service (IPMS) in Mizusawa, Japan. The annual summary report on the PZT time and latitude observations in 1977 has been published.

A long baseline interferometry system (LBI) is being developed in cooperation with York University to test a new more precise and versatile tool for global geodynamic studies. The radio technique using extragalactic sources is potentially superior to the optical astronomical and satellite doppler systems since it combines high precision, sensitivity and long term stability.

Analysis and comparison of the routine and experimental observations of the Earth's rotation and polar motion is used to improve data reduction models, reference standards and observation techniques. Complete re-evaluation of all available PZT observations at Ottawa (1956-78) and Calgary (1968-78) is under way using a new general computer program to analyse data reduction model parameters and variations in the Earth's rotation in the last two decades. Satellite doppler reduction software is also upgraded to increase precision in satellite orbit and pole position determinations.

High quality tidal tilt data observed in an underground site at Glen Almond, Quebec, are being used for comparison with data from a more active seismic region and from less stable observation vaults. Tidal tilt data from the seismically active region of Charlevoix, Quebec, continue to show significant changes in rock response with time. Investigations are underway to determine whether these changes are due to variations in regional crustal response or to changes in local tilt-strain coupling. Tidal gravity data were recorded at the Pacific Geoscience Centre, Sidney, B.C., to provide predictions of time changes in gravity for laboratory applications. Water levels have been monitored in nine different boreholes at Chalk River, Ontario, and Whiteshell, Manitoba, for the purpose of estimating tidal response. Testing and development of computer programs for modelling the tidal response in terms of regional hydrological parameters is underway. The study is designed to reveal possible discontinuities in rock masses for radioactive waste disposal investigations.

Dynamics of the Earth

Semi-annual resurveys of precise gravity networks in seismically active areas in the St. Lawrence valley and Vancouver Island were continued under

contract to the Earth Physics Branch by private industry. Evidence for long-term trends that may be of tectonic significance is now emerging at some stations in both areas against a background of 5-10 μgal ($1 \mu\text{gal} = 10^{-8} \text{ m/s}^2$) seasonal variations. A six station precise gravity profile was established in the vicinity of the LG-2 dam in Quebec to provide baseline data for the measurement of the vertical deflection of the crust due to loading by the LG-2 reservoir. First-order level control along the profile was also updated by the Geodetic Survey of Canada at the request of the Earth Physics Branch in preparation for the filling of the reservoir. The reliability of precise gravity measurements has been improved by routine application of laboratory calibration factors for all microgravimeters presently in use.

Monitoring of strain and tilt data at the Charlevoix observatory near La Malbaie, Quebec, is continuing. Examination of the spatial coherence of tilt in the vault has allowed observed variations to be classified as either "local" or "regional" in character. The "local" variations can be modelled as deformations of the vault itself under the influence of surface temperature variations and episodes of flooding. Statistical analysis of the temporal relationship between "regional" transient tilt-strain events, earthquakes and episodes of high rainfall has shown that neither earthquakes nor rainfall completely explain the observed events. Additional tilt observations are now being made at a distance of 8 km from the main observatory to verify the "regional" character of the events. Monitoring of water levels in boreholes underway at the main observatory also promises to provide a sensitive method of distinguishing between surface run-off and tectonic volume strain. Repeated special order levelling provided by Laval University under contract to the Earth Physics Branch shows systematic tilt of several microradians over a period of five months that is consistent with tilt data from the observatory vault. The activities at Charlevoix are designed to determine the relationship of aseismic deformations to the seismicity of the region while at the same time refining instrumental and siting techniques for use in other areas.

All available tide gauge and releveing data for the Canadian landmass have been collected and computerized by the University of New Brunswick under contract for the Earth Physics Branch. These data have been analysed to provide a smoothed first approximation to the regional variations in vertical crustal velocity in Canada.

Preparations for LOREX 79, the Lomonosov Ridge Experiment to be conducted in the spring of 1979, were continued. They consisted of coordination of the scientific program involving six EMR agencies, one agency from Environment Canada, and five universities; negotiations with the Department of Defence for assistance with the airlifting of bulk supplies; and coordination of logistics and scientific plans between LOREX and the US-sponsored operation FRAM 1 that will be operating concurrently in the Fram Basin of the Arctic Ocean. In October a planning meeting was held at the EPB with all the principal investigators, and representatives from PCSP, EPB and DND present. The first two issues of the LOREX Newsletters were distributed. A final operational plan for LOREX was prepared.

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