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Report of Activities of the Earth Physics Branch during fiscal year 1979-80

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Report of Activities of the
EARTH PHYSICS BRANCH
during fiscal year 1979-80.

K. WHITHAM, Director-General

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 date 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, 1980, 19 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 1979-80, EPB expenditures amounted to $8.04 million, with an additional $507K

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

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 seismological 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 1979-80 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 1979-80 review period, observations were being recorded at 18 standard and 23 regional stations. During the review period the standard station at Fort St. James, B.C. was closed and changed to a regional station at a new location. The regional station at Windsor, Ontario was closed and moved to Effingham, Ontario. A temporary regional station was operated at Burlington, Ontario from December 1979 to April 1980.

The Eastern Canadian Telemetered Network provided telephone line or radio link transmission to Ottawa from eight outstations including Fitzroy Harbour, Ontario, in cooperation with Ontario Hydro; Manicouagan and Gentilly, Quebec, in cooperation with Hydro-Quebec; and La Grand 2 in cooperation with La Societe d'Energie de la Baie James. During the review period, two of the outstations at the La Grand 2 reservoir were closed following the filling of the reservoir, and the borehole seismograph near Glen Almond, Quebec was brought on-line using radio telemetry. 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 requirements for eleven additional stations planned for installation in the next two years.

Seismological Studies of Earth Dynamics

In 1979-80, 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. During the review period, fourteen small to moderate earthquakes were reported felt in eastern Canada, in the region from St. John, New Brunswick to Hamilton, Ontario. The largest, magnitude 5 in the Charlevoix region of Quebec on August 19, 1979, was felt in Quebec, New Brunswick and Maine. Magnitude 5 earthquakes were also felt in the southwestern Yukon and eastern Northwest Territories.

A temporary seismograph was operated at Burlington, Ontario for four months to study a repetitive source of tremors reported from that city. From the seismographic data scientists were able to confirm the source to be small earthquakes and not an air-borne sonic phenomenon. The earthquakes may be related to release of high horizontal stresses in the near-surface rock.

Special investigations of significant Canadian earthquake zones have continued. As part of the joint venture with Foothills Pipe Lines (South Yukon) Ltd., a six-week microearthquake survey was conducted in the autumn of 1979 along a 40 km portion of the Shakwak fault near the south end of Kluane Lake. The low magnitude earthquakes were shown to be scattered throughout a 15 km wide fracture zone bounded by the Shakwak fault on the northeast. An analysis of the focal parameters of the August 19, 1979 Charlevoix earthquake has produced a fault plane solution in excellent agreement with the planar pattern of microearthquakes located by the special array network that has been monitoring the region since 1977. The evidence suggests that the stress in this region is being released on steeply-dipping pre-existing faults in the Precambrian beneath the St. Lawrence river.

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. New attenuation relations for strong seismic ground motion have been derived for application throughout Canada. Contour maps are being prepared to display peak acceleration and peak velocity at a variety of risk levels. The results of this research, if and where appropriate, will be incorporated into new seismic zoning maps to be referenced by a future edition of the National Building Code. 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. One explosion at each of the north and south shore shot points were set off in June and September, 1979. A fifth shot at the north shore shot point was used to measure near source signals. Long term changes in travel time continue to occur; the maximum to date is 46 $\pm$ 11 milliseconds. Two small earthquakes may have been associated with changes of travel time of about 10 milliseconds, but no significant changes were associated with the August 19, 1979, magnitude 5 earthquake.

As part of the integrated geophysical studies in the joint AECL/EMR program of research on geological disposal of radioactive waste, the Service undertakes studies of the variation of compressional and shear wave propagation velocities as a function of depth and azimuth at designated research areas. A test was made of a weight drop device as a source of shear waves at Chalk River. Considerable shear wave energy was recorded at distances up to 600 metres, but much of the energy may have been converted from compressional energy at the basement rock interface. High resolution seismic reflection surveys are conducted to identify and map major shear zones at depths of up to 2 km within granitic batholiths.

A consortium of Canadian Universities and the Earth Physics Branch form a group (COCRUST) cooperating in crustal scale refraction and reflection surveys. In 1979 the group extended its study of the Churchill-Superior boundary by completing three 200 km reversed refraction profiles and 40 km of 1200% common-depth-point reflection work in Saskatchewan and Manitoba.

The Service completed a crustal scale refraction survey of the Lomonosov Ridge in May, 1979 as part of the LOREX program. Near the north pole the Ridge is composed of a thin veneer of sediments overlying a root of mainly oceanic basalt with a maximum thickness of about 27 km. The adjacent basins have very different crustal thicknesses even though separated by only the 65 km width of the Ridge. The Makarov Basin has a thickness to upper mantle of about 12 km sub-sea, whereas the crust of the Fram Basin appears to be 16 km in total thickness.

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.

GEOTHERMAL SERVICE

Geothermal Studies of the Canadian Land Mass

During 1979-80 studies of the thermal state of the Canadian landmass continued to be concentrated in areas of current resource exploration and development. These include the western platform and Rocky Mountain foothills, where exploitation of warm water in sedimentary rocks is possible, the western mountain, where other kinds of geothermal energy exist, and northern regions where permafrost constitutes a hazard to hydrocarbon production.

The capability of measuring the radioactive heat generation of rocks was enhanced by the acquisition of replacement equipment, including a diode gamma-ray detector and the associated analysing and counting circuitry. This facility, with one member of the Service, was moved to the Pacific Geoscience Centre.

A study of existing data from oil and gas wells has shown strong geothermal contrasts in the platform area of the Prairie Provinces. In addition to the mass of low quality temperature data from normal well logs, more reliasble data from producing areas has been collected and heat flow values have been calculated. The northern parts of British Columbia and Alberta show a much higher heat flow than the southern platform, and the main cause seems to be associated with large scale water migration. Such thermal patterns are believed to have changed considerably since the Laramide orogeny.

As a part of Lorex 79, 42 thermal gradiometer observations were made in the vicinity of the North Pole; 22 in the Makarov Basin, 10 on the Lomonosov Ridge and 10 in the Fram Basin. A new lightweight digitally recording Bullard-style thermal gradiometer with 7 thermistor sensors spaced at 40 cm intervals commonly gave sediment penetrations of 3 m using 45 kg of lead weight in water depths to 4200 m. Bottom water temperatures and water temperature profiles were collected over the ridge and the two adjacent basins. Using the transient needle probe technique over 300 thermal conductivity measurements were made on 21 gravity cores.

Assessment of Canadian Geothermal Energy Potential

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

During 1979 pumping tests, hydrofracture experiments and temperature logging were performed in the geothermal production well on the campus of the University of Regina. Pumping tests showed that the permeability of the basal

clastic rocks is more than adequate to supply the flow-rate required for the planned demonstration project. Water samples were collected for chemical analysis, and draw-down pressures were monitored. Hydrofracturing experiments yielded data on the mechanical stress field of the rocks near the contact of Paleozoic and Precambrian rocks. Temperature logs showed that temperatures are slightly lower than predicted, revealing a local variation greater than anticipated, but the high volume of water available compensates for the low temperature.

At Meager Mountain the major programme was performed entirely by the British Columbia Hydro and Power Authority, partly financed by the Federal-Provincial Agreement on Renewable Resources. Technical advice was provided by Energy, Mines and Resources personnel. The project continued to progress, a temperature of 202°C being encountered at a depth of 365 m, in rocks showing evidence of hydrothermal action. This result indicates the presence of a hydrothermal system of unknown size and production capability.

Applied Permafrost Research

The Geothermal Service has continued to monitor temperatures at many of the 100 available well sites in the permafrost region of Canada. The data set is reaching a completeness which warrants analysis in terms of past climates and terrestrial heat flow; a study of mining sites in the Ungava area of Quebec has been completed and published. Data acquisition is continuing in the Yukon and Keewatin areas of the North and is commencing in the Rocky Mountains, again associated with resource development.

In 1979, 10 holes were hydraulically drilled to depths of 30 m at the artificially drained lake site in the MacKenzie Delta. These, and 14 holes previously drilled, contain temperature cables that are being monitored to observe freezing of the previously unfrozen lake bottom sediments. The accompanying landform developments, segregation of ice and associated phenomena are being studied in association with the University of British Columbia and the University of Waterloo.

Under the Energy Research and Development Program, a number of contracts with universities across Canada have been continued, investigating topics related to aspects of frontier hydrocarbon development. The projects generally contribute to physical understanding of water migration in frozen and freezing soils by studying such physical properties as permeability, unfrozen water content, isotope redistribution and thermal parameters. In the past year, for instance, a time-domain reflectometry technique has been developed to measure the unfrozen water content of frozen soils. Investigators studying physical properties of gas hydrates are being supported under the same funding. The immediate concern is to assure sufficient knowledge to identify hydrate horizons and to quantify proportions of hydrate present, and thus to assess hazard to drilling and northern production. In the long-term such horizons may add significantly to our gas reserves.

The joint Industry-Government working group on permafrost and hydrates continues to help identify deficiencies in northern applied research and to provide a forum for discussion on proposed northern development particularly in offshore areas.

PACIFIC GEOSCIENCE CENTRE
W.G. Milne, Chief Scientist

The members of the Marine Geology and Geophysics Group of the Geological Survey of Canada and of the Divisions of Geomagnetism, Gravity and Geodynamics, and Seismology and Geothermal Studies of the Earth Physics Branch share the facilities of the Pacific Geoscience Centre (PGC) in the Institute of Ocean Sciences, Patricia Bay. There are a number of programs in which the two Branches are involved jointly, for example in Resource Charting and studies of the Winona Basin and the Queen Charlotte fault zone. Within the Pacific Geoscience Centre the administrative group serves both Branches, and the technical support personnel cooperate extensively. The Earth Physics Branch component forms part of the Division of Seismology and Geothermal Studies; one new program at PGC, geothermal research, was begun this year with the transfer of a staff member from Ottawa.

SEISMOLOGICAL SERVICE

Monitoring of Seismic Ground Motion

The Western Canadian Telemetered Network (WCTN) operated throughout the year except for a period in February when the operating system in the computer was modified to accept additional stations. The recorders for WCTN, the PGC standard station, tidal and tiltmeter recorders, and geomagnetic field recorders all operate within an open space where they can be viewed by the public. In 1979 approximately 9,000 visitors were shown through the Institute including this area. Since late March visitors have been able to see the tens of events being recorded each day from the volcano Mt. St. Helens. The network of strong motion accelerographs has been maintained throughout the year with servicing under a contract on the mainland, and by PGC personnel elsewhere including the units in the Yukon and Northwest Territories.

Seismological Data Management

Information on the significant earthquake phases recorded on the PGC Standard Seismic Station, the regional stations at Mica in southeastern B.C., Skidegate on the Queen Charlotte Islands, and Gold River on Vancouver Island, and the WCTN stations of southwestern B.C. has been forwarded to Ottawa for routine event location. The epicentres within the WCTN station array are also located at PGC using the USGS Hypoellipse program and are included in the bimonthly report. Intensity data have been gathered for all significant events. A review of the epicentres and mechanisms of the larger older events is in progress. Data from the tape file of Canadian and adjacent offshore earthquakes have been supplied to a number of other research groups and to firms engaged in seismicity or earthquake risk studies.

Seismological Studies of Earth Dynamics

There were five earthquakes felt within British Columbia in 1979/80: November 09, November 15, November 26, November 29, March 07, 1980. The latter event (magnitude 5.1) was centred south west of Gold River, and felt over a wide area but caused no significant damage.

Information and advice has been supplied to engineers concerning earthquake risk for specific sites, structures, or areas in the region. The methods of evaluating and presenting earthquake risk are currently under review. The main active earthquake source areas have been identified and maps have been prepared showing the ground motion expected from these sources with

various probabilities. These revisions to the methodology of computing seismic risk are now being presented to the engineering community for comment.

Seismological Studies of Earth Structure

Several data sets of seismic refraction and deep reflection offshore are currently being worked upon both at PGC and at the U.B.C. Dept. of Geophysics and Astronomy. Of particular interest is a detailed study of the evolution, structure and geological history of the Winona Basin, west of Vancouver Island. In 1979 a land station and ocean bottom seismograph program for microseismicity and seismic refraction was operated on and west of the southern Queen Charlotte Islands. Data from an earlier Resource Charting program identify the Queen Charlotte transform fault as actually a zone of two faults separated by a terrace some 30 km wide. The current microseismicity was found to be occurring on the fault nearest the Islands. Attempts are being made to model the seismic refraction data across the fault zone. Studies of theoretical techniques for the analysis of seismic data are also continuing.

GEOTHERMAL SERVICE

A gamma-ray spectrometer for measuring the natural radiation and thus radioactive heat production of rock samples was moved from Ottawa to PGC in 1979, and is in the process of being interfaced to the PDP-11 which processes the WCTN earthquake data.

Following detailed geological and geophysical studies, a test hole was drilled in the Meager Mountain geothermal area under a Federal-Provincial agreement. It encountered encouraging high temperatures (over 200°C at 370 m depth). Further drilling of this potential energy source is planned. Other areas of the Cordillera are being examined for geothermal energy potential in the course of regional geothermal studies.

GEOMAGNETIC SERVICE

Operation of Magnetic Observatories

The operation of the Victoria Magnetic Observatory has continued at the NRC/Dominion Astrophysical Observatory Site. A magnetometer is operated at PGC on public display to provide data to mining exploration companies and others doing magnetic surveys.

Geomagnetic Studies of Earth Structure

The data from the recent deployment of automatic-retrieval Ocean Bottom Magnetometers on the Juan de Fuca ridge have now been analysed. These results, which are the first to be obtained over an active deep-sea spreading ridge, have provided important new restraints on the temperature and distribution of melting in the oceanic upper mantle. Land based magnetometers were deployed across the Cascade volcanic chain in central Washington State, in cooperation with the University of Washington. An electrical conductor at shallow depth in the earth approximately aligned with the volcanic centre has been located. Measurements are now being made in the area of the currently active Mount St. Helens. A similar program across the Leech River fault on southern Vancouver Island has failed to show evidence of any significant electrical conductivity contrasts on the no longer active fault system.

GRAVITY SERVICE

Gravity Mapping

The data from the 1978 Resource Charting Parizeau Cruise west of the Queen Charlotte Islands are now reduced, and contour maps of levels of gravity and geomagnetic anomalies (G.S.C.) are complete. The 1979 Resource Charting Parizeau cruise operated in Hecate Strait. Data from the second year of a three year contract to upgrade gravity coverage in the Rocky Mountain region has been monitored, checked and accepted.

GEODYNAMICS SERVICE

Dynamics of the Earth

The Nano-gravity lines to monitor slow vertical ground motion on northern Vancouver Island were resurveyed twice in 1979. Anomalous gravity readings continue to persist. Levels of ground water or lake water have been shown to alter the gravity field, but these do not account for the total change, and vertical ground motion or a crustal redistribution of mass is suggested to explain the results. Studies of the plate tectonic interactions along the margin of western Canada have continued with analyses of both the north and southern portions of the Juan de Fuca plate system. Work has continued on the design and construction of a hydrostatic tiltmeter system for detection of long term tilt.

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 1979-80 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 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 operation of the AMOS installations is checked daily by telephone from Ottawa.

A prototype of the new Automatic Magnetic Observatory System, AMOS III, was subjected to exhaustive tests at the Ottawa Geomagnetic Laboratory. Under the control of a microprocessor, it carries out various tests on the data being recorded and stores diagnostic messages, mean hourly values, ranges and a limited amount of one-minute data for interrogation from the control centre by telephone.

Under the Cooperative Projects with Industry (COPI) program, a contract was awarded to EDA Instruments Inc. to develop a production version of AMOS III for the international market. A complete commercial prototype was built and tested, and a technical description of AMOS III ("System Overview") was published. Drafts were prepared of the Installation Manual, the Operator's Manual and the Servicing Manual. Work had not been started on the development of diagnostic software routines when the contract expired.

International Magnetospheric Study (IMS)

The Geomagnetic Service operated by contract through 1979-80 nine magnetic variation stations as a contribution to the International Magnetospheric Study 1976-79. Although the IMS ended 31 December, 1979, the stations will continue in operation until 30 June, 1980, to provide data for the magnetic survey satellite MAGSAT program. 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, 8 magnetic repeat stations were reoccupied by contract in Quebec and Ontario during May and June. In October, 8 more stations, from Nova Scotia to British Columbia, were occupied by Branch personnel, to begin a new schedule of secular variation surveys as recommended by an internal evaluation study. The national network of repeat stations has been reduced in number from 112 to 58, the recording period is lengthened to 3 or 4 days, and the stations will be occupied in the autumn if possible. Seven of the 16 stations occupied in 1979 form part of a worldwide ground support network for the MAGSAT program. These stations will be reoccupied at two-year intervals over the next 6 years.

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 1978 from all AMOS stations and preliminary 1979 tapes for most stations were sent to World Data Center A, and to geophysical exploration companies on request.

IMS Data

Processing of the digital data for 1979 from the Churchill array of variation stations was essentially completed by the end of March 1980.

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. As an experiment, a telephone answering system was rented, and three-day predictions recorded in English and French were available from May 22 to September 30, 1979. During this period 513 calls were registered, mainly during evening or early morning hours. A questionnaire indicates that the automatic telephone system is greatly preferred over telex or CBC broadcasts, methods which were tried in previous years. A telephone answering system has been purchased to provide short-term predictions and information on the actual magnetic activity from May to November, and to provide 28-day predictions during the winter when there is little geomagnetic exploration activity.

Magnetic Charts

Recent secular variation measurements indicate that Canada is still under the influence of the large impulse of secular change which affected a large part of the northern hemisphere in the early 1970's. The rate of change of magnetic declination has doubled in Western Canada. The centre of rapid increase in the horizontal component, which in 1975 was located a few hundred km southeast of Nova Scotia, has moved to southern Quebec, and has weakened from 100 nT per year to 80 nT per year. The vertical component is now decreasing over most of Canada, ranging from -10 nT per year at Resolute Bay to -120 nT per year at Ottawa.

The magnetic declination chart of Canada, epoch 1980.0, was prepared for publication. The declination values shown were derived from spherical harmonic representations of the north and east horizontal components, using a computer program developed at E.P.B. for applications in gravity mapping.

Paleomagnetic Data

Good progress was made in updating the paleomagnetic data catalogs in a new format designed to simplify bilingual publication. Several review papers presenting scenarios for the relative movements of major continental blocks as derived from paleomagnetic measurements were published.

Geomagnetic Studies Of Earth Structure

Paleomagnetism

Paleomagnetic research has been concentrated on two interesting regions - Appalachia and the Cordillera. Studies of the magnetization of Newfoundland and New Brunswick rocks of Siluro-Devonian age suggest that a rather extensive shift of the magnetic pole relative to Appalachia occurred during this interval. The origin of the polar shift is being investigated by examining the magnetization of rocks of the same age span from cratonic North America, such as the Lower Paleozoic dyke swarm and alkaline intrusives related to the St. Lawrence rift system. The study is expected to provide an evolutionary scheme for the tectonic history of the Appalachian region. In the Cordillera, paleomagnetic investigations of four groups of rocks from western British Columbia indicate that the Stikine block and Wrangellia were formed considerably to the south of their present position relative to cratonic North America. Significant rotations of miniplates appear to have occurred as these fragments were joined to the continent.

Electromagnetic Induction in the Earth

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

A limited region of very low electrical resistivity at shallow depths in the earth's crust has been located near the village of Ste-Mathilde, Quebec. In cooperation with Ecole Polytechnique of Montreal and the Geological Survey of Canada, estimates of the depth and areal extent of the anomalous zone have been made by magnetotelluric, audio-magnetotelluric and Schumberger DC resistivity observations. One-dimensional modelling techniques indicate that the upper part of the conducting body lies at depths between 250 and 1000 m and that it is a few kilometers thick. This anomaly is associated with very

large attenuation of the telluric field and apparent resistivities which lie well below 1 ohm-metre.

During Project LOREX in April and May 1979, magnetotelluric stations were established at each of the three manned drifting camps and operated for a period of six weeks. Good data were obtained along the drift paths over the Makarov Basin, the Lomonosov Ridge and over the Fram Basin. Over the ridge the data indicate only a very thin cover of soft or unconsolidated sediments underlain by more resistive material. However over the Fram and Makarov Basins these conducting soft sedimentary layers are about 1 km thick. There is no evidence for a highly conducting core or lithosphere associated with the ridge.

Long Wavelength Magnetic Anomalies

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

Geomagnetic Disturbances

The occurrence characteristics of substorms appearing at invariant latitudes greater than 79° and the movement of associated ionospheric electrojets were investigated. These substorms appear mainly in the winter months during the descending phase of the sun-spot cycle. The substorms generally are localized and occur on days of moderate magnetic activity. The diurnal variation of their occurrence reflects the proximity of the station to the poleward edge of the auroral bulge in the midnight-dawn sector. A study of several selected events suggests that electrojets may occur simultaneously at the equatorward and poleward edges of the auroral oval.

Detailed analysis of data from the Churchill array ground stations and from a rocket launched southward across two bright auroral arcs disclosed intense electric currents flowing northeast on the poleward edge of the northern arc, and southeast along the equatorial edge of the southern arc. Large field-aligned currents, exceeding the topside critical current density by a factor of 6, flowed outward above the arcs. The electric field in the northern arc was periodic and appeared to be related to oscillations in the aurora.

Long series of hourly values of the magnetic components from 12 observatories have been analysed by the Chapman-Miller method to obtain the solar and lunar harmonic coefficients. Altogether some 450 observatory-years of data with nearly 12 million hourly values have been divided into classes according to various geophysical parameters, and the significance of these results is under investigation.

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 1979 more than 3000 new static gravity stations were occupied over the Canadian mainland and offshore areas and about 19,000 line kilometres of dynamic gravimeter profiling were logged off the east and west coasts of Canada and in the Arctic Ocean. In western Canada 325 new gravity stations were observed in the Rocky Mountains south of latitude 53°N, about 750 gravity stations were observed at 1 km intervals along the Dempster and 60-mile highways in the Yukon and over 800 gravity stations were observed at 1 km intervals between Lethbridge, Alberta and Osoyoos, British Columbia, following highway route No. 3. More than 4600 line kilometres of gravity profiling were completed in Hecate Strait east of the Queen Charlotte Islands. Profile separation was 5-10 km.

Over 700 gravity values were acquired near the North Pole as part of the Lomonosov Ridge Experiment (LOREX 79). About 400 line kilometres of gravity profiling was completed using instrumentation installed at three ice island campsites, which drifted across the ridge. More than 250 additional stations at 5 km intervals were established by helicopter traversing. A survey on the frozen surface of Hudson Bay between the Ottawa Islands and the mainland produced 429 new gravity stations.

In eastern Canada about 14,000 line kilometres of gravity profiling was completed over the Scotian shelf about 550 km southeast of Halifax. Profile separation averaged about 40 km.

Gravity Standards and Gravity Data Base

A joint Canadian - Italian - U.S. experiment to determine gravity meter calibration correction functions was carried out over twelve absolute stations between Catania, Italy and Hammerfest, Norway. Statistically significant second order calibration correction terms appeared in some meters, but differences between gravimeter derived gravity values and absolute values were unexpectedly high (up to 80μgal) at several sites. The cause is as yet undetermined.

The reobservation of the first order National Gravity Net (some 60 stations and their related excentres) began early this year. The readjustment will yield more precise gravity values for future geodetic and secular variation studies. The work will be carried out partially under contract and is scheduled for completion in mid-1980. The maintenance service for IGSN71

and the Latin American Network (LAGSN77) continued but at a somewhat reduced level from previous years.

Some 400 retrievals from the National Gravity Data Base were processed during the past year for both internal and external users. Three new open file gravity maps were released during the year.

In collaboration with the Geodetic Survey of Canada a study of the absolute accuracy of the vertical reference datum was undertaken for gravity stations in older surveys. A comparison of the differences between the originally measured and modern heights of some 1700 stations in hinterland areas of Quebec and the Northwest Territories suggests that systematic elevation errors as great as 3 m may exist in some areas. Analysis of this problem will continue.

Gravity Studies of Earth Structure

A full colour shaded bathymetric and topographic relief map of the area of the Juan de Fuca plate has been completed. It is also available in contour only and grid only versions at the same scale. Compilations of seismicity, earthquake fault plane solutions and geomagnetic sounding stations are being prepared on the same base at the Pacific Geoscience Centre.

An analysis of offshore Pacific geophysical data indicates that the migration of the Explorer Ridge to the northwest and the initiation of the Dellwood Knolls spreading centre may be part of a triple junction which has controlled recent structure in the Winona Basin - Tuzo Wilson Knolls area over the last 4 Ma. A detailed sequential plate reconstruction suggests the existence of an extinct spreading centre near the end of Paul Revere Ridge and a small active left-lateral transform fault between this point and the continental margin near Scott Islands.

Magnetic anomaly analysis over the Gorda Plate off southern Oregon suggests that an active right-lateral fracture zone may exist within the plate and that convergence in the area immediately north of Cape Mendocino stopped at about 1.5 Ma.

Interpretation of gravity data over the Queen Charlotte Fault Zone and over the Winona Basin supports P-wave velocity models that show up to 5 km of sedimentary material beneath each structure and, in the case of the fault zone, suggests the existence of a sliver of older crust lying between the two boundary scarps.

Three reviews were prepared for the Geodynamics Project Final Reports series to be published by AGU. The first was prepared jointly by PGC, UBC and some U.S. institutions for Working Group 2 and assesses the geodynamics of the Juan de Fuca plate. The second and third were written at EPB for Working Groups 8 (passive margins) and 10 (global syntheses and paleoreconstructions) and deal with the structure and tectonic evolution of the polar continental margin (WG8) and the Arctic seafloor (WG10).

Initial gravity model calculations from LOREX 79 indicate an average Lomonosov Ridge density not greater than about 2.45 g/cm^3, not typical of oceanic type rocks.

An analysis of detailed gravity and crustal seismic data along two lines along the major axes of the Sverdrup Basin indicates, among other things, that basin sediments are regionally compensated by a mantle antiroot and that the thickness of the crystalline crust varies inversely with that of the overlying sediments. These features may be caused by crustal stretching that produced a subsiding sedimentary basin which was balanced isostatically by an upwelling of dense mantle material.

A joint E.P.B. - Concordia University gravity-magnetic study of the Sutton Gravity High near Sherbrooke suggests that the anomaly can be explained by up to 8 km of volcanic rocks thought to be a remnant of the opening of the Iapetus ocean at a triple junction of which the failed arm is the Ottawa graben.

A series of regional gravity anomalies in the eastern Churchill province of the Canadian Shield has been ascribed to the existence of major faultbounded crustal blocks. The inferred crustal structure lies to the east of the Labrador Trough, considered to be the site of an ancient subduction - collision zone, and may have a modern equivalent in the central Andes of Peru where similar regional crustal structures are present and the Nazca plate actively thrusts below the South American plate to the west. By analogy, the geological development of the Churchill province may be related to underthrusting of an oceanic plate that brought the Superior block into contact with the Churchill block.

Recent marine gravity surveys in eastern Hudson Bay show that the pattern of paired positive and negative gravity anomalies along the Cape Smith foldbelt extends southwards to the Belcher Islands. Interpretation of five gravity profiles across this zone suggests that the Churchill crust is thicker and denser than the Superior. To the north volcanic rocks of the foldbelt are estimated to be between 4 and 9 km thick. To the south foldbelt rocks are generally 6 to 7 km thick. Collision between the Churchill and Superior blocks during the Lower Proterozoic (Aphebian) is supported by paleomagnetic results for Belcher Islands rocks which can be interpreted in terms of a two-plate model.

The prominent positive-negative gravity anomaly pairs along Precambrian structural boundaries in Canada produce gravitationally induced stresses that may contribute to the failure of rocks along pre-existing zones of weakness. Failure at shallow depths in the crust is likely in the region outlined by the negative gravity anomaly whereas failure at deeper levels may occur beneath the positive anomaly. Along the heavily faulted lower St. Lawrence Valley, good spatial correlation between seismic epicenters and free air anomaly lows that are adjacent to prominent free air gravity highs suggests that gravitationally induced stresses may be a contributing factor to the production of earthquakes in this region.

In 1977 and 1979 gravity measurements were made at several levels in two goldmine shafts sunk in the Archean Yellowknife greenstone belt to determine the in situ densities of basic volcanic rocks of the Kam Formation, Yellowknife Supergroup. Densities computed from the gravity results, 2.79 g/cm^3 and 2.81 g/cm^3, are somewhat lower for each shaft than density values, 2.82 g/cm^3 and 2.93 g/cm^3, obtained from rock samples collected at the underground gravity stations. The gravitationally derived densities reflect the high proportion of sheared rocks and the presence of lower density members of the Kam Formation in the immediate vicinity of the shafts. A density of 2.90 g/cm^3 is considered to be representative of the Kam Formation as a whole.

The results of a gravity survey carried out on the frozen surface of Great Slave Lake suggest that the Yellowknife greenstone belt extends offshore for some 12 km and then swings southeast along the North Arm of the lake for a further 60 km. A three-dimensional model of the greenstone belt derived from the gravity anomalies indicates that mafic volcanic rocks of the Kam Formation are generally 1 to 3 km thick and reach a maximum of 7 km at the mouth of Yellowknife Bay. Sedimentary rocks of the Burwash Formation are generally 1

to 3 km thick. The presence of a pluton of granodiorite flanking the belt to the southwest is also inferred.

About 240 gravity stations were observed at 2 km intervals and 134 rock samples were collected in northern Saskatchewan to test the feasibility of the gravity method for locating uranium deposits. The survey is part of a program sponsored by the Nuclear Energy Agency and International Atomic Energy Agency. Asamera Oil and Gas Corporation Limited and Numac Oil and Gas Company Limited have respectively provided 2,500 and 1,000 previously established gravity stations to this study.

A 2-D program for gravity interpretation has been updated by the addition of a plot package, which allows the user to plot cross-section, terrain, observed gravity, calculated gravity, and residual gravity at specified scales in a variety of combinations. By the proper choice of scales for horizontal and vertical distances, plots ready for publication can be produced. The program for 3-D gravity interpretation has been updated to provide a printer plot of gridded values and to format the output for automatic contouring by GPCP.

A second test to determine the capability of the LaCoste and Romberg inertial platform to measure positions on solid surfaces has been completed with the following results (one sigma): elevation, 120 cm; horizontal position, 20 m; gravity, 0.3 mgal. A third test to extend the results to helicopter operations is planned.

Radioactive Waste Disposal Program

Geophysical activities within the Department's Radioactive Waste Disposal Program continued to be coordinated by the Division. A master contract for reconnaissance geophysical surveys was established and directed from the Division and activities under this contract began late in the year for AECL research areas at Pinawa, Manitoba and Atikokan, Ontario. Further detailed gravity and seismic surveys were run at Chalk River, Ontario and the task of monitoring the response of water levels to earth tides continued in several drill holes there. Seismic velocity measurements in the field were compared with velocities determined on drill core subjected to pressures up to several thousand atmospheres, to evaluate the effects of cracks and fractures. These and related tasks are continuing and will be synthesized to produce case history accounts of the geophysical characteristics of each research area. The data will also be considered as contributions to the evaluation of rock quality and integrity within the concept evaluation phase of the program.

GEODYNAMICS SERVICE

The Generation and Management of Geodynamic Data

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

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

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

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

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

Dynamics of the Earth

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

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

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

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

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