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Report of Activities

of the

Earth Physics Branch

during fiscal year 1977-78

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Report of Activities of the EARTH PHYSICS BRANCH during fiscal year 1977-78.

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 determine the safety of any radioactive waste disposal program 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.

All the above 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.

During the year the west coast activities of the Branch were gradually transferred from the Victoria Geophysical Observatory to the Pacific Geoscience Centre (PGC) at Patricia Bay, Vancouver Island, the move being completed in February, 1978. Several scientists were moved from Ottawa to PGC

and it is planned to continue to broaden the research base of the group. The work of the Branch will continue in close liaison with marine and terrain geology elements of the Geological Survey of Canada, which also work from the Centre.

With the exception of a relatively small amount of funding from the Environmental-Social Program, the Office of Energy R&D, and the Federal Labour Intensive Program, all resources of the Branch are supplied by the Earth Science Services Program. In 1977-78, ESSP expenditures amounted to $6.96 million, with an additional $515K being supplied by ESP, OERD and FLIP. Personnel allocation for the Branch was 175.5 man-years, of which 87 were scientific and professional. Approximately 15% of the total staff were located outside Ottawa, more than half of them at the Pacific Geoscience Centre.

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 throughout the country. 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 and development related to renewable energy resources; and tectonic processes are investigated to increase our understanding of crustal evolution and resource emplacement.

The 1977-78 seismological and geothermal activities in western Canada carried out at the Pacific Geoscience Centre are reported separately in a later section.

SEISMOLOGICAL SERVICE

Monitoring 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 1977-78 review period, observations were being recorded at 19 standard and 18 regional stations. During 1977 the Baker Lake station was converted from standard to regional and new regional stations were opened near Minton, Saskatchewan, Windsor, Ontario and Chats Falls, Ontario, the latter as part of a cooperative project with Ontario Hydro. The Eastern Canadian Telemetered Network provided telephone line transmission to Ottawa from outstations at Maniwaki, Montreal and near the Manicouagan reservoir, the latter in a cooperative project with Hydro-Québec, with whom arrangements were

also made for a telemetered station near Gentilly, Quebec, with operations commencing in April 1978.

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 on a daily basis. Development work has continued on transmission of data from the borehole seismometer near Ottawa to the Division's data laboratory for recording and analysis.

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. Late in this review period, the data processing laboratory was undergoing reconfiguration and expansion to accommodate additional telemetered stations that will become operational in 1978.

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.

Seismological Studies of Earth Dynamics

In 1977-78, 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.

During 1977, Service personnel responded to many inquiries from the press and the general public concerning earthquakes and other phenomena. The year was, however, a quiet one for Canadian earthquakes with no earthquakes greater than magnitude 4 occurring compared to ten such events in 1976. On August 8, two earthquakes of magnitudes 4 occurred within three minutes of each other on the north shore of the St. Lawrence River southwest of Sept-Iles; these were felt along the north shore and in the Gaspé. On February 18, 1978, an earthquake near St.-Donat-de-Montcalm, Quebec was felt throughout the Laurentians and as far away as Montreal and Ottawa. Minor reports of felt earthquakes were received from locations such as Fredericton, New Brunswick, Ste. Emile and Ste. Agathe, Quebec, Willmore Provincial Park, Alberta and Sandspit, Richmond and Victoria in British Columbia.

The temporary seismograph array installed near Windsor, Ontario in 1976 to analyse earth tremors felt in the area in recent years continued operation until March, 1978, at which time it was replaced by a regional seismograph station. Evidence accumulated during this investigation has suggested that

the tremors felt by local residents resulted from industrial explosions on the U.S. side of the Detroit River.

Service personnel operated two temporary seismograph stations in Cornwall, Ontario in December 1977 to check possible earthquake origins of the tremors being felt in that city. No significant ground disturbance was associated with the tremors and it was concluded that they originated from ice contraction on roofs of buildings during rapid temperature drop. Also during December, Service personnel became involved in tracing the origins of sonic booms in southern Nova Scotia and the U.S. east coast. All available evidence suggested that the booms were caused by supersonic commercial and military aircraft.

The Yellowknife seismological array was employed in an attempt to locate the impact location of the COSMOS 954 satellite. To test the sensitivity of the array to this type of seismic source, weighted barrels were dropped from an aircraft southeast of the array and the data carefully analysed to detect the resulting signals. It was concluded that the impact did not produce sufficient seismic energy to permit the array to assist in the location.

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. The induced seismicity at the Manic 3 reservoir has decreased to a very low level and the six-element array was removed in August 1977. Monitoring continues with the Manicouagan telemetered station. Monitoring of pre-loading seismic activity at La Grande has continued and plans are being made for three telemetered stations to monitor the reservoir loading in the Autumn of 1978.

Special investigations of significant Canadian earthquakes have continued. The relocation studies of the earthquakes in the Charlevoix region of the lower St. Lawrence have revealed that the larger earthquakes occurred at the extreme ends of a 70-km long zone trending along the river. Research on the seismicity of southern Saskatchewan has shown a spatial correlation of the earthquakes with salt solution structures and the structurally disturbed areas of the Precambrian basement. Studies of Beaufort Sea earthquakes have shown that the important tectonic forces in the region are due to uncompensated surface sediments and possibly to stresses transmitted from the active Nansen-Gakkel spreading ridge.

The Seismological Service responds to numerous requests for information on seismic risk from engineers, various government agencies and the general public. An assessment of low probability seismic risk has been completed for eastern Canada and research has commenced to assess the methodology and parameters to be employed for a new seismic zoning map of Canada. Service personnel continue to be active in a Canadian Standards Association Technical Committee to establish a new standard of seismic design requirements for CANDU nuclear power plants, and in the Reactor Safety Advisory Committees of the Atomic Energy Control Board. Low-level seismic monitoring is being done in cooperative projects with Ontario Hydro and Hydro-Québec at existing and potential sites for 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 have continued as part of a broad range of geophysical studies of this active zone. Two more explosions were set off in the region in August 1977 as part of the continuing series to monitor travel-time and velocity changes that may precede a large earthquake. To date, only small variations in travel-times have been detected, about twice the size of the estimated timing error. An array of six stations was installed in the Charlevoix region in October, 1977. The detected microearthquakes continue to be distributed throughout the 70 km long zone and correlations with other geophysical measurements are being attempted for the larger events.

An interpretation of seismic refraction data from the Arctic Archipelago has revealed crustal thicknesses which vary from 40 km beneath the eastern Sabine Peninsula to 32 km west of King Christian Island. Regions of seismic wave scattering correlate very well with a major series of dykes and the area of recent earthquake swarm activity.

In a cooperative project with the Universities of Manitoba, Saskatchewan, Alberta and Toronto, Service personnel undertook a seismic refraction and reflection experiment in Manitoba and Saskatchewan as part of a continuing program to study the nature of the boundary between the Churchill and Superior provinces of the Canadian Shield. With the University of Manitoba acting as the coordinating agency, 500 km of refraction and 80 km of reflection profiling were obtained in August, 1977 near the boundary zone.

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 detailed lateral seismic survey at the AECL Chalk River property in October, 1977. Horizontal velocities of seismic waves were measured as a function of azimuth from a central borehole. Variations in velocities and attenuation are related to tidal stresses, pore pressures and the distribution of cracks and joints in the rock body.

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 underground nuclear explosions. Analyses of a number of seismic events, predominantly underground nuclear explosions, were performed in 1977-78, often in cooperation with seismological research groups in the United Kingdom and Sweden. The Yellowknife array detection bulletin has been made available to research groups in the United States and United Kingdom for studies of rapid detection and location of seismic events.

The Ad Hoc Group of scientific experts sponsored by the Conference of the Committee on Disarmament in Geneva completed its report on international cooperative measures to detect and identify seismic events. Service officers represented Canada in the meetings of this group, which will continue in 1978 with detailed planning of seismic data exchange procedures.

GEOTHERMAL SERVICE

Delineation of the Geothermal Regime

The thermal state of the youngest part of the Canadian land mass, the western mountains, has been pursued by several means. Measurements of radioactive heat production have been made on rocks from plutons in the Yukon

east of the Tintina Trench, from central British Columbia and from sites where heat-flow measurements have been made. Heat flow measurements have been made by oceanic techniques in the deep fjords of the west coast between 52°N and 56°N. Although limited by the extent of the fjords, these measurements provide the opportunity to obtain valuable information where no drilling has been done. All measurements in the Cordillera provide valuable background data for the search for sources of geothermal energy.

Laboratory studies of the thermal properties of rocks from other areas were conducted and data management services including the dissemination of information to national and international agencies were maintained.

Geothermal Studies of the Canadian Landmass

In 1977-78 the Geothermal Service completed a study of the thermal state of the very old crust of the central part of the Canadian Shield. Although levels of natural radioactivity in the rocks are now low, they were much higher when the shield was formed, and temperatures were probably at least as high as those found in young crust today. This thesis is supported by the high grade of metamorphism and diapiric plutonism observed in the present surface rocks. The temperatures and rock properties measured during this study are valuable data in the research into safe disposal of wastes from nuclear reactors. The thermal conductivity of the rock is now being related to mineral content in order to be able to predict the behaviour of rocks under artificial thermal conditions.

As a result of a cooperative study with Department of Indian and Northern Affairs and the National Research Council a preliminary paper has outlined areas of potential gas hydrate occurrence, the hazard posed in hydrocarbon development by their presence, methods of identification and mitigation of the hazard, and the potential of hydrates as an unconventional source of natural gas.

A study of the thermal state of the crust of the Maritime Provinces was also completed in 1977-78. This area was subject to large scale granite intrusion in Paleozoic time and shows a corresponding high heat generation in some areas.

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 the background information that is essential to the recognition of areas of geothermal potential.

During 1977 a shallow drilling programme was completed in the Garibaldi Volcanic Zone of southwestern British Columbia. It was shown that the area close to Meager Mountain is hotter than adjacent areas. Geological mapping and age dating of volcanic centres was continued and electromagnetic and magnetotelluric techniques have been examined as geothermal exploration tools.

The geothermal potential of the deep sedimentary formations below Regina has been examined by the Energy Research Unit of the University of Regina under contract. Previously existing data from oil and potash industries indicates that water production rates from the deepest and hottest permeable rocks will be ample to supply heating for large institutional buildings. Typical peak heat supply rates of 5 MW should be easily achieved, provided the water supply is maintained by pumping. The water will contain about five

times as much salt as sea water, and heat must be transferred to a secondary circulating system through heat exchangers. The cooled geothermal water will then be reinjected into the source formation from which it came at a sufficient distance from the producing well. Typical temperatures of the water beneath Regina are 70-75°C, which is not hot enough for generating electrical power but is quite adequate for space heating. This project should lead to the first demonstration of geothermal energy utilisation in Canada, which will also be the first use of 'renewable energy resources' at the Megawatt level.

Thermal Studies for Environmental-Social Program - Arctic Pipelines

The Geothermal Service has continued investigation of the thermal profiles through permafrost at 100 locations primarily in the Arctic Islands and the Mackenzie Valley. During the past year a further volume of the collected data for northern wells has been published. Various physical properties of the permafrost can be deduced through the logging of each well several times after completion and subsequent analysis of the rate of dissipation of the drilling disturbance. The theory developed for the investigations has been presented in several papers published or in press and has been used to investigate problems facing the mining and oil industries in the north.

In the Spring, 22 holes were drilled from the sea-ice of the Beaufort Sea using a hydraulic jet-drill. One group of holes in the cooperative programme with the Geological Survey of Canada was sited to outline the relationship of degrading sub-sea permafrost and gas hydrates to the Mackenzie Canyon, Mackenzie River outflow and ocean temperatures and salinities. The second group was placed to examine the position of the permafrost table in an area where shoreline recession rates due to thermal erosion are well documented.

The Service continued its coordination role in thermal and moisture migration studies associated with environmental-social studies of potential northern development. The studies have included contract research on the distribution of stable isotopes in and the hydraulic conductivity of frozen soils. Research on the thermal regime beneath northern rivers and the shallow thermal regime of the Keewatin region has been undertaken by other cooperating government agencies, and continued shallow thermal measurements on- and offshore Byam Martin, eastern Melville Island and Cornwallis Island in the high Arctic have been made by the Service. The shallow thermal studies have been augmented by extensive measurements of the thermal properties of encountered soils and rocks.

PACIFIC GEOSCIENCE CENTRE

W.G. Milne, Chief Scientist

The Pacific Geoscience Centre was designated in May, 1977 as the centre on the west coast of Canada within which the western geophysics programs of the Earth Physics Branch and the western marine geology and geophysics programs of the Geological Survey of Canada would be operated. The wing housing the Centre in the Institute of Ocean Sciences at Patricia Bay near Sidney, British Columbia was occupied in early 1978. Programs, which are outlined below, are components of national geophysics or geology programs, and frequently constitute joint studies by the two Branches of EMR. 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.

SEISMOLOGICAL SERVICE

Monitoring Seismic Ground Motion

The Western Canadian Telemetered Network (WCTN) operated for part of the year at the Victoria Geophysical Observatory where the seismic data from Haney, Port Alberni, North Pender Island and Victoria were recorded. The recording facility was moved to the Pacific Geoscience Centre (PGC) in early 1978 at which time the Victoria sensor was replaced by one on the new site. The Victoria standard seismic station was also moved to the PGC site at this time. The network of strong motion seismographs continued in operation and was increased to 98 with the addition of four accelerometers on northern Vancouver Island. None of these was triggered during the year.

Seismological Data Management

Information on P phases of all earthquakes is telegraphed routinely to Ottawa for onward transmission to data centres. The data on local earthquakes gathered by regional or standard stations and by WCTN are reported for inclusion in the listing of Canadian earthquakes.

Seismological Studies of Earth Dynamics

Four minor earthquakes were felt in the vicinity of Vancouver Island. None of these required study beyond a routine location.

Additional data have been discovered for the earthquake of February 14, 1918 which was originally located near Revelstoke, British Columbia. The new information indicates that this event was probably located 200 km north of Mica Creek, near the Rocky Mountain Trench.

A review paper describing the seismicity of western Canada and related tectonics has been published. The paper has defined the currently active earthquake areas of the region and correlated these with other known geological and geophysical information.

A brief field program was operated near Rocky Mountain House in south western Alberta following the identification of a series of minor earth tremors. The data gathered indicated that the events were small, but felt over a limited area in which water is being routinely injected for the production of gas.

Research continues on the methods of defining seismic risk. The current seismic zoning map in the National Building Code of Canada makes use of ground acceleration amplitudes for the design of earthquake resistant structures; theoretical studies are exploring the use of other perhaps better parameters. During the period the Service responded to numerous requests for site specific calculations from engineers in both the public and private sectors.

Seismological Studies of Earth Structure

Two cruises were undertaken during the period by scientists from the EPB and the GSC to study the structure and the seismicity of two areas west of Vancouver Island. In the first survey EPB scientists successfully deployed and recovered four 'pop-up' ocean bottom seismographs and detected some minor earthquakes. Subsequent acoustic sounding from the ship revealed a 20 km wide zone which has been named the Nootka Fault along which it is believed there has been recent movement.

The second cruise using ocean bottom seismographs and air gun techniques studied the region near the spreading centres further west of the Nootka Fault near the Dellwood Knolls. The objective of the experiment was to map earth structure in an area where new crust is being generated.

Theoretical studies are being continued on the lithospheric structure of the earth by computing times and amplitudes of seismic waves and comparing them with observed data. This experiment has permitted the positive identification of certain phases from the offshore seismic programs. The technique also enables the identification of low velocity layers in the earth which cannot be mapped by normal methods.

GEOTHERMAL SERVICE

Geothermal Studies of the Canadian landmass

Scientists from the Service in Ottawa and Victoria participated on a ship's cruise in the fjords along the coast of British Columbia. Data were gathered in the autumn and the exercise will be extended in the spring to examine the seasonal variation in the heat flow measurements due to a change in the run-off cycle of local fresh water. Scientists from the Geological Survey of Canada on the same cruise gathered bottom samples, and ran seismic reflection profiles across the same fjords.

A new heat flow probe, capable of making nearly continuous observations from a slow-moving ship, was designed, built, tested and used to make a series of measurements along profiles west of Vancouver Island. The instrument is used to study the hydrothermal conductivity in the earth's crust along the edges of sedimentary basins, along structures of old rock and along the new material at the ridge crests.

GEOMAGNETIC SERVICE

Operation of Magnetic Observatories

The Victoria Magnetic Observatory continued to operate in a satisfactory manner. No change in this function is contemplated as a result of the move of personnel to the Pacific Geoscience Centre.

Management of Geomagnetic Data Base

Data from the Victoria Magnetic Observatory are routinely gathered by the AMOS system, but the original equipment is maintained and reduced as required to fill in gaps on the tapes. Forecasts and current levels of magnetic activity are supplied to private or public firms on request.

Geomagnetic Studies of Earth Structure

Broad-band magnetotelluric and magnetic depth sounding data were interpreted for the Lillooet Valley - Meager Creek region of southwestern British Columbia. These data will, when completely analysed, provide information on the physical size and properties of the source of the geothermal region. Geomagnetic variation studies across the Cascade Volcanic Belt at Garibaldi and in cooperation with the University of Washington near Mount Baker and Mount Ranier have revealed a major difference in the conductivity structure of the northern and southern sections.

An investigation of electrical conductivity in volcanic areas of the Cascades continued as a cooperative project of the Pacific Geoscience Centre and the University of Washington. Major differences are evident between the geomagnetic variation data from lines crossing the volcanic belt of southern

British Columbia and central Washington State. An anomaly in the 1 to 15 minute period range exists on the southern line but no equivalent anomaly is observed on the northern line. The area between the existing profiles is being investigated to determine the position of the anomaly boundary and its tectonic implications.

During the Pacific Geoscience Centre Cruise 77-6, the three ocean-bottom magnetometers designed and built in Ottawa were deployed and recovered from a depth of 2,500 metres. The sites were selected in the region of the Dellwood Knolls, a proposed spreading centre of the north end of the Juan de Fuca Plate northwest of Vancouver Island. Useful data on the magnetic variations at the ocean floor were recovered from all three instruments.

GRAVITY SERVICE

Gravity Mapping

A land gravity survey on Vancouver Island, the Queen Charlotte Islands, and parts of the British Columbia mainland at a station spacing of 5 - 8 km was carried out under contract and supervised from the Pacific Geoscience Centre. Preliminary steps were taken to award a contract for the gravity survey in the Cordillera region. A relief map of topography and bathymetry of the Juan de Fuca region covering an area from northern Vancouver Island to northern California was prepared to act as a base for geophysical studies of the region.

Gravity Studies of Earth Structure

Detailed interpretations of the structure across the continental margin of British Columbia and Washington showed how gravity and seismic data can be combined in a model involving a dipping lithospheric plate. In particular, such a tectonic model supports the presence of a high-density low-velocity layer beneath Vancouver Island. Investigations and analysis have been made of recent fault patterns and trends on Vancouver Island, to show their relationship to the general tectonic patterns.

GEODYNAMICS SERVICE

Dynamics of the Earth

Support was supplied to this Ottawa based group on their measurement of micro-gravity along two lines on northern Vancouver Island to measure crustal deformation.

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, by telephone, and by telex.

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 River.

GEOMAGNETIC SERVICE

Magnetic Observatories

The 11 magnetic observatories that operated throughout 1977-78 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 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.

In order to reduce operating costs, classical photographic recording was discontinued at Churchill, Baker Lake and Great Whale River, which are now all operated by part-time local contractors. Magnetograms for most of the stations in the network are now plotted by computer from the AMOS data.

Magnetic Surveys

As part of a continuing study of the magnetic secular variation, 31 of the 100 carefully marked repeat stations uniformly distributed over the Canadian landmass were reoccupied in the summer of 1977, in northern, central and eastern regions. For the first time, a private contractor did part of this work (21 stations). Absolute measurements of magnetic declination, inclination and total intensity were made at each station, usually over a period of a few days, while a portable recording magnetometer provided a

continuous record of the variations of the magnetic field.

A detailed magnetic survey was completed of the harbour at Kingston, Ontario, where an intense local magnetic anomaly has interfered with marine navigation for two centuries. Measurements were made on the ice over several years in early spring, during the short periods of suitable weather.

A towed proton-precession magnetometer was again installed on the C.C.G.S. NARWHAL, as a contribution to the multi-disciplinary survey of Hudson Bay organized by the Ministry of Transport. Approximately 10,000 kilometres of total intensity profiles were obtained.

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. Final tapes for 1976 and preliminary tapes for 1977 containing one-minute digital values from all AMOS stations were also sent to the World Data Center, and to geophysical exploration companies on request. Significant reductions in data-processing costs were achieved through more efficient computer programs, the integration of secondary digital recordings into the editing process, and the plotting of data directly on microfilm. The magnetic observatory yearbook for 1975 was published, in completely bilingual format for the first time, and the manuscript of the 1976 yearbook was completed in the English version.

Forecasts of Geomagnetic Activity

As a service to geophysical exploration companies, electric power companies and pipeline companies, the Ottawa Magnetic Observatory issues two types of forecasts of geomagnetic activity: a 27-day forecast prepared at three-week intervals and distributed by mail, and a 72-hour forecast, prepared twice a week and available by telephone or telex.

Magnetic Charts

An evaluation was made of the secular variation terms of the International Geomagnetic Reference Field 1975, a mathematical model of the earth's magnetic field adopted internationally in that year. A comparison of the changes observed at 130 magnetic observatories with the changes predicted by the model revealed large discrepancies over many parts of the world, and in particular over a large part of North America. Very rapid changes are occurring in the Maritime Provinces, associated with an intense centre of secular variation now located in the North Atlantic 1,000 kilometres east of Newfoundland and moving towards Canada.

Paleomagnetic Data

Fifteen global maps summarizing the drift, according to paleomagnetic data, of the major continental blocks since the Devonian have been published. They indicate that a redistribution of the continents occurred at the end of the Paleozoic era. This episode of continental drift appears to coincide with the world-wide extinction of certain species of life, and the development of oil-rich structures around the North Atlantic Ocean. Maps of tentative reconstructions of the earlier Paleozoic world are in press.

Geomagnetic Studies of Earth Structure

Magnetic Anomalies

A review has been written of published magnetic surveys over the Arctic Basin. The many uncertainties in the data preclude a full compilation of the observations in a single format. An interpretation of the high-level airborne data over the Greenland end of the Nansen-Gakkel Ridge suggests a spreading rate of 8 millimetres per year during the last 3 million years, and a spreading rate of 14 millimetres per year during the preceding 7 million years. The pattern of magnetic anomalies over the Alpha and Mendeleev Ridges is quite different from that over the Nansen-Gakkel Ridge, and is similar in some respects to patterns over continental shields. A strongly positive magnetic anomaly of very long wavelength characterizes the Alpha Ridge, while the Nansen-Gakkel Ridge and most active spreading ridges have associated weak positive or negative anomalies of very long wavelength. On the other hand, the magnetic pattern of the Alpha Ridge may be the result of a series of imbricate subduction zones and related island arcs.

Paleomagnetism

During 1977-78 paleomagnetic results from the following Precambrian formations have been published: the Harp Lake Complex, the Labrador Trough, the Rapitan Group, the Gowganda and Chibougamau Formations and the Abitibi Greenstone Belt. Publications on the Pearson Formation of Great Slave Lake, and the Jacobsville Formation of Michigan were in press. An intensive study of three collections of rocks from the Belcher Islands of Hudson Bay was completed. Laboratory work on many other Precambrian collections is in progress.

A contract was awarded for the first year of a four-year paleomagnetic study of the Sudbury Basin. It is believed to be the first time in Canada that private industry has undertaken paleomagnetic research.

From the Lower Paleozoic, a detailed study of the red sandstones of Minudie Point, Nova Scotia, has been published. It provides a reference point for the Carboniferous Basin of Eastern Canada. A study of the Lower Ordovician Connemara Suite of Western Ireland has been published, and several other investigations of Lower Paleozoic formations have been submitted to journals.

An extensive paleomagnetic investigation of the Cordillera has been undertaken. In a joint project with the Geological Survey of Canada, the Takla Group, the Asitka Group, the Mazelton Group and the Axelgold Intrusion have been sampled, and laboratory measurements have begun. The experimental work for a study of the Kamutzen Formation has been completed.

Several papers interpreting combined results of many paleomagnetic studies have been published. For example, all published Archean results have been used to sketch an Archean polar path. Aphebian results indicate that an event of folding and subsequent remagnetization may have affected a wide region from Quebec to Minnesota prior to the intrusion of the Nipissing diabase 2,150 million years ago. Data obtained so far are consistent with the idea that Laurentia has remained intact for at least the last 2,200 million years. The Jacobsville Formation and Rapitan Group results have led to a reinterpretation of Late Precambrian paleomagnetic data and the discovery of the Hadrynian Polar Track. The data support the hypothesis of an integral single plate unit for Laurentia and Grenvillia.

A puzzling feature of the earlier apparent polar paths is the apparent absence (or neglect) of high-latitude poles. One of the reasons for this may be that it is extremely difficult to show that a high-latitude pole represents an ancient magnetization while the assumption that it is attributable to remagnetization in the present earth's field is so easily accepted. Often a pole obtained from a magnetization with high blocking temperatures and/or high remanent coercive forces may be regarded as anomalous because it does not fall on an existing polar path, even though that path may have been drawn originally as tentative. Following the discovery of Hadrynian and Aphebian high-latitude poles, other high-latitude poles found in Lower Paleozoic results have been re-examined and used to propose new and totally different apparent polar paths. Clearly, since so many different interpretations can be put forward on the available data, the data base is inadequate and more data of high quality are needed to resolve those differences.

Electromagnetic Induction

Magnetotelluric fields have been monitored for over 3 years near the centre of seismicity in a tectonically active region in Charlevoix County on the north shore of the St. Lawrence River. The results indicate that electrical properties of upper crustal layers are strongly time-dependent in this area, and changes of more than 30% in the impedance tensor have been detected over a period of a few months. However, the most important part of the measured time-dependence appears to be a trend of increase in impedance of about 14% per year. There have been only two earthquakes greater than magnitude 3.0 in the area since recording began in 1974 and it has not been possible to develop a clear association between this low-level seismic activity and resistivity changes. Seasonal variations in the temperature and salinity of the nearby St. Lawrence River may be a contributing factor. Much less change in impedance was observed at similar MT recording stations located outside the zone of seismicity. Two new recording sites have been established near Baie St. Paul and La Malbaie to study the distribution of time-dependent effects and their relationship to earthquake occurrence.

The monitoring of magnetotelluric fields at three stations in the vicinity of the Manic-3 dam was continued to study electrical parameters of the crust in an area of induced seismicity. An increasing trend in impedance was observed at one of the stations (Outardes) over a 19-month recording interval but no significant changes were evident at the other sites. The induced seismicity has gradually died away and experimental work was terminated in August 1977.

Interpretation of the 3-component magnetometer data obtained in 1976 across Banks and Victoria Islands, in terms of the electrical conductivity structure of the earth in this region, indicates that the crust of western Banks Island is highly conducting and possibly of oceanic origin. Thus the change to more resistive continental crust occurs in central Banks Island and also marks the eastern boundary of the Mould Bay Anomaly. The transfer function amplitudes for long-period magnetic variations (one hour) decay slowly toward the southeast until at Cambridge Bay no significant transfer function is recorded at any period. However, at shorter-period variations (10 minutes) they decay to zero in northwestern Victoria Island but are enhanced again over the Precambrian uplift known as the Minto Arch which indicates significant upper crustal lateral variations in conductivity.

Published magnetotelluric results from the Arctic Basin for periods less than two hours were analyzed to determine electrical conductance of sub-bottom materials (presumably sediments) under Wrangel Plain, Chukchi Rise, Lomonosov

Ridge, East Siberian Shelf and Nansen-Gakkel Ridge. From these conductances, using a model for the conductivity profile, up to 4 kilometres of conducting materials (sediments) are inferred beneath the Chukchi Rise and Wrangel Plain locations. These thicknesses are consistent with determinations from seismic studies. Between 1 and 4 kilometres of sub-bottom conducting materials are derived for two East Siberian Shelf locations. Lomonosov Ridge, displaying a relief of 2.9 kilometres is believed to be wholly composed of conducting materials (sediments or volcanics). The Nansen-Gakkel Ridge has less than 0.5 kilometres of conducting materials.

Four-layer conductivity models which fit the observed long-period (> 2 hours) apparent resistivity curves obtained recently by Soviet investigators have provided a range of depths to and conductivities of an upper mantle conductor under the Chuckchi Rise, Lomonosov Ridge and Wrangel Plain. The models studied here provide an uncertainty in estimating the depths (about ± 15 percent) and conductivities (factors of 10). No upper mantle conductor could be detected beneath the Nansen-Gakkel Ridge location.

An ocean-bottom magnetometer was designed and three units were built. The magnetometer records digital samples of three orthogonal geomagnetic components on cassette tape. The outputs of two inclinometers are also recorded on the cassette to provide tilt information for determining the orientation of the three fluxgate sensors. One cassette tape will record for three weeks at the one-minute sampling period usually selected. For deployment, the magnetometer is packaged in a 0.6 metre aluminum sphere which is dropped overboard with a concrete anchor attached. At a preset time the sphere is released from the anchor and floats to the surface. A flashing light and a radio transmitter attached to the sphere aid in finding and retrieving the instrument. Only nine months had elapsed from the initial design to the successful application of these instruments, as described in the Pacific Geoscience Centre section of this Report.

Geomagnetic Disturbances

Solar and Lunar Variations

The computer program to determine M2-tide by the Chapman-Miller method has been extended to include computation of N2 and O1-tides as well. The program has been used to re-analyze Sodankyla hourly geomagnetic data (1914-1966) from which international disturbed days have been excluded. A report has been prepared giving solar and lunar harmonic coefficients for a variety of different geophysical conditions. Similar computations for Nurmijarvi station using 1953-73 geomagnetic hourly data are in progress.

In cooperation with the Computer Science Centre, an edit program was prepared to check various kinds of errors which are found in the hourly data on magnetic tape. The program will be valuable for checking geomagnetic and meteorological hourly data before they are used in analysis. A comprehensive report is being prepared for distribution.

A detailed analysis was published of the Sq current system, based on data from over 100 magnetic observatories for the 8 most quiet days of the International Geophysical Year. The analysis was a joint project with the U.K. Institute of Geological Sciences.

Pulsations

Further analysis of the data from the joint University of Alberta - Earth Physics Branch magnetometer array experiment of 1972, when 42 instruments recorded magnetic variations in north central USA and south central Canada, shows that magnetic pulsations in the period range 45 to 600 seconds suffer a

regional distortion similar to that already reported for substorms and the daily variation. The anomalous fields arise from internal currents flowing in a linear conductive body in the Central Plains of North America. Above the conductor, the variations in declination have amplitudes more than twice those at locations 300 kilometres to the east or west. The variations in the vertical component are also enhanced and undergo a reversal of phase from one side of the conductor to the other.

A study of the longitudinal and latitudinal characteristics of Pc4 and Pc5 micropulsations throughout the daytime sector using a network of 20 Canadian stations (12 operated by Earth Physics Branch, 7 by University of Alberta and 1 by University of Saskatchewan) is underway. The digital data from the Churchill chain of stations in 1976 have been edited for analysis and event tapes made. Amplitude-time stack plots reveal that there were intense Pc5 pulsation activities around the middle of October 1976. This was then followed by four consecutive days of Pc4 giant pulsation activities. These events will be spectrally analysed and studied in detail. The possibility of detecting pulsations by means of digital polarization detectors based on Stokes' vector-algebra representation is being investigated in cooperation with the National Research Council.

Cleft and Auroral Currents

Models of the electrojets for the post-noon rocket launchings into the cleft on November 25 and 28, 1975 revealed both discrete and distributed currents causing magnetic perturbations of approximately 100 nT on the ground. The north-south meridian current was very dynamic and its changes were used to determine Birkeland currents. These field-aligned current densities were 10-20 $\mu A/m^2$ and are of the same order as the critical current of the topside ionosphere at approximately 5,000 kilometres. They were coincident with the position of several faint arcs. The Joule heating of the upper atmosphere was determined and significant heating was found to occur in the cleft region as well as in the auroral zone.

Preliminary analysis of the VB-39 rocket data indicate very intense field-aligned currents occur along with auroral fluctuations, which may have been curls. The rocket flew across an auroral breakup that occurred during the decay phase of a substorm on the 29th of February 1974. Large, rapid magnetic perturbations, which were measured by ejected spin probes, were of the order of 2,000 nT, while the auroral fluctuations were determined from the auroral scanner. These magnetic perturbations indicate that field-aligned currents are greater than 100 $\mu A/m^2$, probably exceeding the critical current and causing instabilities in the topside ionosphere.

International Magnetospheric Study (IMS)

The Geomagnetic Service continued to operate 9 temporary magnetic variation stations as part of the program for the International Magnetospheric Study (IMS). These stations along with a few standard magnetic observatories 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 analogue recorders as well. During 1977-78, six of the stations were also equipped with new microprocessor-based telemetering systems, which radio the data to Boulder, Colorado, via US weather satellites. In all, some 24 magnetic stations are included in the satellite

relay system, which provides real-time monitoring of magnetospheric conditions to indicate when other IMS experiments are to be performed.

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 geologic 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

In 1977-78 approximately 25,000 line-kilometres of dynamic (shipborne) gravimeter profiling were completed and 5,800 static gravity measurements were observed on land and ice-covered coastal regions. The shipborne survey in Hudson Bay was carried out in cooperation with the Canadian Hydrographic Service in the northern half of the bay and was designed to complete the interlining of the 45 km track spacing, begun in 1975, to a 10 km interval. During February and March, 1978 in another cooperative survey with the same agency 1,400 gravity stations were observed at 6 km intervals on the frozen surface of Hudson Bay, south and east of the Belcher Islands.

In British Columbia about 700 gravity stations on Vancouver Island, Queen Charlotte Island and adjacent areas of the mainland were established by contract. Elsewhere in the province, about 900 gravity stations were observed on the highway between Prince George and Edmonton, Alberta and along the Alaska Highway between Fort St. John and Fort Nelson. This survey, carried out by contract, was undertaken to support a requirement of the Geodetic Survey Division, Surveys and Mapping Branch, for gravity information related to the upgrading of precise elevation networks. Station spacing for this survey was 1 km.

In the Northwest Territories a helicopter-supported party observed more than 1,300 gravity stations in the western half of Viscount Melville Sound. This survey, supported by the Polar Continental Shelf Project, was carried out in cooperation with the Canadian Hydrographic Service. In Lancaster Sound, a signature line, consisting of 35 stations at 4 km intervals situated 25 km offshore from Maxwell Bay, Devon Island, was observed in response to a request from the Atlantic Geoscience Centre for datum control for shipborne gravity surveys.

In Quebec, more than 1,300 stations were observed by contract in the eastern townships and Gaspé regions to upgrade and densify previous work. Average station spacing throughout the entire region is now about 6 km.

Systems Development

Research in dynamic gravimetry continued with the testing of the LaCoste & Romberg dynamic gravimeter as a possible alternative to the recently available Inertial Survey System (ISS). Two tests have been made principally to determine the system's ability to measure elevations when operated in the same mode as the ISS. The results to date indicate that elevations may be observed with a standard error not exceeding 3 m and generally less than 1 m.

Software which had been developed to detect and correct various system errors by cross-correlation procedures is currently being extended to provide real-time corrections using Kalman filtering techniques.

Map Production

Eleven open files, made up of gravity anomaly maps and associated digital files, were released in 1977.

Gravity Standards and Gravity Data Base

The systematic inspection and updating of control stations of the National Gravity Net was continued by contract in Alberta, Saskatchewan and Manitoba. A total of 225 stations were visited and 53 were replaced. Updated gravity values and base descriptions for the area are now available on request.

Pilot studies on the use of System 2000 (S2K) for the four files comprising the National Gravity Data Base were completed. The control station file was brought into production under S2K and the design work completed for the conversion of the anomaly file. Significant improvements in data management flexibility at no increase in cost are resulting from these conversions.

Updating of approximately 800 IGSN71 station descriptions was completed and copies sent to the International Gravimetric Bureau in Paris for distribution. The Latin American Gravity Standardization Net (LAGSN77), compiled and adjusted over the past four years, was presented to the Geophysics Commission of the Pan American Institute of Geography and History at the XI General Assembly held in August 1977 at Quito, Ecuador. A resolution was passed formally adopting this network as a gravity reference standard for Latin America.

During the year, advice and assistance was provided to the Ontario Ministry of Natural Resources in the processing of data from a gravity survey in the Timmins area. Further data processing assistance was provided to the National Observatory of Brazil which is updating and extending the national gravity network for Brazil.

The National Gravity Data Base incorporates gravity and related data obtained by departmental surveys or contributed by external agencies. In response to 123 requests received during the past year from government agencies, exploration companies and universities, the Gravity Data Centre retrieved and distributed 128 million characters of information, mostly in the form of magnetic tapes. Approximately 12% of the requests required preparation of digital anomaly maps. Also, 350 descriptions of reference stations were requested. In support of in-house field and research programs, an additional 161 requests were processed, involving the retrieval of 27 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.

Compilations of free-air gravity and bathymetric data for the Arctic Ocean north of 60° have led to the production of four types of free-air maps and a new bathymetric chart that has already generated much interest on the part of the international community, although it is not due for general release until late 1978. Calculated and predicted mean free-air gravity maps of the Arctic provide a reliable first approximation of the gravity field for intermediate scale anomalies; a free-air gravity map derived from satellite data approximates very large scale regional anomalies; and a residual free-air anomaly map is useful for quantitative analysis of crustal structure. The bathymetric map has been compiled at a scale of 1:7,500,000 on a polar stereographic projection to provide a base for geophysical data. It utilizes almost 250,000 digitized water depths, about 7,000,000 values in analogue form and several thousand values taken from plotting sheets made available from various international sources.

In British Columbia, interpretation of the regional gravity field of the continental margin has been pursued in terms of subduction of the Juan de Fuca plate. An apparent contradiction between seismic and gravity-derived estimates of crustal thickness under Vancouver Island has been resolved by postulating the existence of high density/low velocity material such as amphibolite above the down-going slab of ocean lithosphere in the arc-trench gap.

The analogue model of plane indentation was applied qualitatively to the proposed collision of the Slave craton with the western Churchill craton of the Canadian Shield. The model predicts several large scale deformational features of the collision zone. In James Bay the results of a gravity survey suggest that the Kapuskasing Gneiss Belt may be tectonically linked to the proposed circum-Superior suture. Both structures may have been formed during collision of the Churchill and Superior cratons in late Aphebian time.

Gravity measurements were made to a maximum depth of 1600 m in two goldmine shafts sunk in basic volcanic rocks of the Yellowknife Supergroup to determine bulk densities of surrounding rocks. The mines were the Giant "C" shaft of Giant Yellowknife Mines Limited and the new Robertson shaft of the Con Mine operated by Cominco Limited. The densities thus obtained will be used in the interpretation of the gravity field associated with the Yellowknife greenstone belt.

A direct gravity formula employing a telescoped polynomial in latitude has been derived to calculate theoretical gravity for the Geodetic Reference System 1967. A procedure to screen or select gravity data from a larger data set has been programmed using the binary positions of the computer word to expand greatly the effective computer memory. A study of the horizontal and vertical changes in gravity, geoidal height and deflections of the vertical was completed using a structural model of a granitic batholith as a basis for the computations.

Studies of the effects of high temperature and pressure on crustal rocks were focussed on field studies at Lac à L'Eau Claire (Clearwater Lake) crater, Québec, and at the Haughton structure, Devon Island, N.W.T. At the former, studies of crustal melting and the magnetic properties of strongly deformed and heated rocks were carried out in collaboration with scientists from NASA Johnson Space Center and the Lunar Science Institute. Joint investigations of trace elements with scientists from the Enrico Fermi Institute, Chicago and the Max-Planck Institute, Mainz, indicate that the Clearwater East and Brent craters were probably formed by the impact of stony meteorites. At the Haughton structure a gravity survey was conducted along with a study of

shocked rocks from within the 20 km structure. Comparative studies of material shocked in the laboratory and at sites of underground nuclear explosions continued.

The program of evaluating geophysical methods to be used in the assessment of possible sites for the disposal of radioactive waste continued in collaboration with other branches of the department. The test site provided by AECL on their Chalk River property was the scene of seismic and magnetotelluric field surveys designed to test rock quality and the presence of significant fracture zones. A 270 m drill hole on this site was thermally logged and several anomalies associated with fractured rock were detected. Cores from the drill hole were examined in detail to determine thermal, petrofabric and rock crack properties for evaluation of the field studies.

GEODYNAMICS SERVICE

Generation and Management of Geodynamics Data

Polar Motion

Computer automated astronomical (PZT) and satellite Doppler observations from the Polar Motion Observatories near Ottawa and Calgary have continued to provide data for the international earth rotation and polar motion monitoring services. The Canadian PZT results have been transmitted weekly to the International Time Service (BIH) in Paris and monthly to the International Polar Motion Service (IPMS) in Mizusawa, Japan. The continuous excellent data quality is reflected in the top weights assigned to the Canadian measurements in the BIH system (Ottawa and Calgary are ranked 1 and 2 respectively). The satellite Doppler observations of the navigation (NNS,TIP) and geophysical (GEOS, BEACON) satellites have been transmitted daily to the Polar Monitoring Service of the U.S. Defense Mapping Agency Topographic Center for routine processing. Both the quantity and quality of the data produced by the Ottawa Tranet station have improved substantially since the beginning of 1977 when the station was relocated to Shirleys Bay and its operations fully automated. The satellite Doppler data from both observatories have been used frequently as a reference for satellite geodetic positioning and network stability studies by government and private agencies in Canada.

Major re-evaluation and analysis of the PZT data from Ottawa (1956-1977) and Calgary (1968-1977) have been undertaken using a specially developed computer program. For this conversion all the rotational time observations have been referred to the atomic time system. The analysis of this unique data set is expected to explore the limitations of the classical optical astronomical technique for geodynamic studies.

Detailed analysis of the modern techniques suitable for monitoring global geodynamics has led to concrete plans for a long baseline interferometry experiment to determine the length of day with a precision exceeding that of current optical methods. The experiment will be carried out by York University under contract to the Earth Physics Branch.

Earth Tides

High quality tidal tilt data continues to be produced at Glen Almond and Charlevoix, Quebec. Analysis and interpretation of the Glen Almond data indicate the presence of a strong topographic effect which is consistent with recently available theoretical models. The Charlevoix tilt data show changes in amplitude which are being investigated in terms of regional and local time varying crustal response to tidal loading. Tidal gravity data were recorded

at both Fredericton and Halifax during 1977-78 as part of a program to map the variations in the gravity tide across Canada using a LaCoste & Romberg earth-tide recording gravimeter. Water level tides have also been recorded at two wells near Ottawa to obtain baseline data on the response of aquifers to the volume strains expected from earthquakes.

Dynamics of the Earth

Precise gravity networks in seismically active areas in the St. Lawrence valley and on Vancouver Island were resurveyed at six month intervals by private industry under contract to the Earth Physics Branch. Examination of the results of repeated surveys yields no evidence for long term trends but there is a seasonal jitter of 5 to 10 μgal (1 μgal = 10^{-8}m/sec^2) at some stations. Careful analysis of the results at coastal stations has demonstrated the importance of correcting for ocean tide attraction effects during these surveys. The internal consistency of a given instrument was improved during 1977-78 by the use of better transportation methods. Exhaustive tests on a calibration range and weight tests in the laboratory revealed a significant and hitherto unsuspected variation of calibration factor over the range of the microgravimeters being used in these precise surveys.

Strain and tilt data recorded at the Charlevoix Observatory near La Malbaie, Quebec are reduced routinely from month to month and analysis and interpretation of the data are now underway. A large annual variation in strain and tilt can now be explained in terms of a thermo-elastic model of the observatory vault. Several tilt/strain events lasting for a day or more have been identified and appear to be related to local seismicity. A more definite interpretation requires further sampling and confirmation from other tiltmeters to be installed in the area soon. An experiment at the Charlevoix Observatory to measure long term tilting by repeated special order levelling is being carried out under contract by Laval University. Preliminary results show that the technique is very promising and complements the less stable short baseline tiltmeters in the observatory vault.

Analysis of laser ranging data to the GEOS-3 satellite for the purpose of recovering the geometric earth tide was completed this year. A dynamic method was investigated that uses short satellite-arcs fitted to several passes of laser data as references from which pass-to-pass movements of a single tracking station can be observed. Although improvements in the geopotential model and in the station co-ordinates of the tracking stations reduced the apparent station-height movements to less than 1 m, reference arcs of longer duration were required and proved to be computationally too expensive. A quasi-geometric method has been found to be more successful. In this method the effects of unmodelled satellite dynamics on the determination of displacements are minimized by considering two-station simultaneous ranging to GEOS-3 at the precise time that the satellite passes through the plane defined by two stations and the centre of mass of the earth. Good agreement has been obtained with the seismologically determined tidal constant for the earth.

Anomalously large wind-induced tilts were measured on an ice floe station in the Beaufort Sea during the AIDJEX project. In an effort to explain the relationship between the large (30 μrad) tilts and drift velocity of the ice, experiments were carried out in a flume in the laboratory whereby simulated ice floes were exposed to wind and currents. Preliminary results show that the tilt observed on the Arctic pack ice could be reproduced in the flume and that for a given floe length the tilt is proportional to the wind stress.

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