49638

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Energy, Mines and Resources Canada
Énergie, Mines et Ressources Canada

Canada

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Report of Activities

of the

Earth Physics Branch

during fiscal year 1976-77

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Report of Activities of the
EARTH PHYSICS BRANCH
during fiscal year 1976-77.

K. WHITHAM, Director General

The Earth Physics Branch is responsible for the Earth Physics Service Activity within the Earth Science Services Program. The objective of this Activity is to ensure the availabiltiy of 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.

To fulfill these objectives the Branch has identified a number of principal missions. Firstly it maintains and augments geophysical data bases with appropriate technology in the fields of seismology, geothermics, geomagnetism, gravity and geodynamics by operating networks of seismological, earth motion and magnetic observatories and by conducting field surveys to improve and complete magnetic and gravity coverage of Canada, to map the geothermal regime of Canada including permafrost, and to obtain paleomagnetic and seismological data in key areas. These geophysical data bases support the other missions of the Branch. The second mission is 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. Thirdly the Branch has a strong mission to assess geological hazards in Canada including earthquakes and permafrost and prediction research where applicable, together with the concomitant understanding of current earth dynamics, i.e., current sea floor spreading, vertical motion, rotation and axial wobble of the earth. The final mission encompasses the application of 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 ensure the safety of any radioactive waste disposal program in geological formations.

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.

In the year under review, severe restraints in money and manpower have continued: consequently more emphasis has been placed on the formal evaluation of Branch projects, the establishment of goals and the organization of planned project work-elements.

The projects conducted by staff from three Services at the Victoria Geophysical Observatory continue to be integrated within the national programs of the Service. Plans are in hand to relocate the Victoria Geophysical Observatory within the newly constructed Pacific Geoscience Centre of the Patricia Bay Institute of Ocean Sciences during 1977, where the work will be continued in close liaison with marine and terrain geology elements of the Geological Survey of Canada, which will also be working 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 1976-77 ESSP expenditures amounted to $6.5 million, with an additional $254K being supplied by ESP, OERD and FLIP. Personnel allocation for the Branch was 176.5 man-years, of which 87 or 49% were scientific and professional. Approximately 15% of the total staff were located outside Ottawea, half of them at the Pacific Geoscience Centre.

HIGHLIGHTS

During the review period, a sensitive broadband seismometer was installed in a 100-metre borehole near Ottawa, the data to be telemetred to the Ottawa laboratory for acquisition and analysis. A temporary seismograph array was also installed near Windsor, Ontario, in an attempt to locate the source of earth tremors felt in that area in recent years. Three ocean-bottom seismometers were deployed off the Coast of British Columbia near active seafloor tectonic centres to aid in studies of ocean crustal structure and seismicity. Velocity ratio and seismicity studies continued in the Charlevoix region to study physical processes in an active seismic region and a refraction survey was conducted on the Beaufort Sea ice.

In the Arctic, measurements of the thermal regime were carried out along the shorelines of Byam Martin and Little Cornwallis Islands, in eastern Melville Island, in the Keewatin, and in the Beaufort Sea. These studies will help to delineate areas of permafrost and allow better predictions to be made. Contract field studies of hot springs and the geothermal potential of deep sedimentary basins were completed, with further work contemplated. The third catalogue of world heat flow data was published by the Branch.

New geomagnetic variometers were installed at Meanook, Victoria and Ottawa, and a new AMOS prototype has been built and tested. A three-component airborne magnetometer survey of Quebec, the Atlantic provinces and the Atlantic continental shelf was made during Sept. and Oct., 1976, completing the present phase of high-level airborne coverage of Canada. Since 1953 over one million line-km have been flown in this survey, and over 24,000 five-minute average values in D, H, and Z collected. Approximately 12,800 line-km of total magnetic field values were obtained in Hudson Bay in July and August, 1976, as part of an on-going multidisciplinary survey.

Geomagnetic studies of earth structure were successfully continued in the southern Coast Mountains of British Columbia and in the Manicouagan Impact Structure, Quebec. An upward continued airborne data set was shown to be in good agreement with a satellite data set; this finding has encouraged international plans for world wide magnetic

surveys by satellite, beginning in 1980. Studies of crustal and upper mantle conductivity anomalies were carried out in the western Arctic, in the Prairie provinces and in British Columbia.

A number of paleomagnetic studies have led to reinterpretations and clarifications of polar paths and ancient continental juxtapositions. New techniques and instrumentation have been developed in the field of paleomagnetism, in which the Earth Physics Branch is an acknowledged world leader. The 3rd, 4th and 5th issues of the review of world-wide paleomagnetic data were published, completing this project.

Studies of geomagnetic disturbances were pursued on a broad front, including pulsations, variations due to solar and lunar influences, aurora and auroral currents; and the Geomagnetic Service continued to cooperate with the International Magnetospheric Study.

Major gravity surveys were carried out off Vancouver Island, in Hudson Bay, in the Beaufort Sea, in Amundsen Gulf, and over much of Nova Scotia. An open file system was introduced for the release of gravity data. The maintenance service for the International Gravity Standardization Net (IGSN71) is now in operation. A compilation and adjustment of gravity control stations in Latin America was completed. An important study of gravity anomalies as related to structural boundaries in the Precambrian Shield focussed attention on the importance of plate tectonics in the Precambrian.

Studies of large Canadian hypervelocity impact sites continued, with stress being laid on comparisons with underground nuclear explosion phenomena. Results of a two-year field experiment were released to show that the technique of nanogravimetry is applicable to the detection of very small crustal movements that could be the precursors of earthquakes.

In cooperation with geophysicists from the Geological Survey of Canada, plans have been developed for the geophysical evaluation of the shape, the structural coherence and competence, and the dynamical stability of potential geological host bodies for radioactive waste disposal. Research into the new techniques which will be needed for these studies is underway.

In the following pages the above projects and studies are reported upon in more detail.

DIVISION OF SEISMOLOGY AND GEOTHERMAL STUDIES

M.J. BERRY, Director

The Division of Seismology and Geothermal Studies is responsible for the Seismological and Geothermal Services of Canada.

The Seismological Service monitors the seismic ground motion in Canada by operating a number of seismograph networks throughout the country. The scientists of the Service use the data from the stations to determine Canadian seismicity and with this knowledge make the best estimates possible of the seismic risk, with special emphasis on those areas around urban centres and regions of industrial development that lie in zones that are earthquake prone. Extensive theoretical studies are also undertaken to supplement the observational program.

The data base is also used to determine the structure of the Canadian landmass and to study the nature of the mantle and core of the Earth. These studies frequently require special field experiments involving controlled sources which may vary from a simple explosion to such complex devices as "Vibroseis" vibrating trucks.

The Service provides advice on a wide spectrum of subjects that involve seismology in one fashion or another. A continuing significant application is the problem of the detection and identification of underground nuclear explosions.

The Geothermal Service conducts research into the thermal regime of the ground in all parts of Canada. For this purpose temperature is measured by lowering probes into deep boreholes, and data are acquired on the thermal properties of rocks and soils. The research is applied in three main directions: the distribution and character of permafrost is examined in order to provide information appropriate to the needs of resource industries and regulatory agencies; geothermal energy resources in Canada are being assessed as part of renewable energy resources R & D; and the tectonic processes are being investigated to increase our understanding of crustal evolution and resource emplacement.

SEISMOLOGICAL SERVICE

Monitoring Seismic Ground Motion

The Seismological Service operates a variety of seismograph stations throughout Canada and is responsible for instrument development and calibration, quality control, and data collection and dissemination. During the 1976-77 period two new regional stations were opened leaving totals at the end of the period of 20 standard stations and 14 regional stations.

The Eastern Canadian Telemetered Network continued operation with telephone line transmission to Ottawa from outstations at Maniwaki, Montreal, and near the Manicouagan reservoir. The Western Canadian Telemetered Network also continued operation with telephone line transmission to the Victoria Geophysical Observatory from Alberni, Haney and Pender Island.

The Yellowknife seismological array continued operation in a stable configuration. Automatic telephone dialing and data transfer facilities are employed to transfer the array event detection log from Yellowknife to an Ottawa computer on a daily basis.

A sensitive broadband seismometer was installed in a 100-meter borehole near Ottawa and development work was undertaken to transmit the seismic signals to the Division's data laboratory for data acquisition and analysis.

The network of 94 strong-motion seismographs continued operation in western Canada. Seven of the accelerographs in the Georgia Strait region triggered during the 16 May 1976, magnitude 5.3 Pender Island earthquake, producing accelerations in the range of 2 to 4 percent gravity.

Seismological Data Management

Information on approximately 30,000 P phases is reported annually by the standard stations. These data are relayed through Ottawa to the international centres for world-wide earthquake determinations. Original Canadian seismograms and data continued to be in demand by national and international research institutions. Part of this demand is met by microfilming Canadian seismograph records for deposition 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 processing laboratory in Ottawa. This 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 data laboratory makes extensive use of the Departmental computing centre.

Both the Eastern (Ottawa) and Western (Victoria) Telemetered Network recording systems have automatic detectors that trigger on, and store 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

The Service continued its study of Canadian earthquakes in 1976-77 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.

The 1976 year was one of numerous damaging earthquakes around the globe and Service personnel responded to many press and public inquiries concerning these earthquakes. Approximately two dozen earthquakes were reported felt in Canada during 1976-77. The 16 May Pender Island earthquake was felt widely in southwestern British Columbia; the 23 October 1976 earthquake near St. Simeon, Quebec, was felt throughout the lower St. Lawrence valley and in Maine and New Brunswick. Minor felt reports of earthquakes were received from such wide-spread locations as Leamington, Ontario, Radville, Saskatchewan, Baffin Island and the Yukon-Alaska border; the latter earthquake caused an avalanche on Mt. Logan. The largest Canadian earthquake during the time period was the 20 December 1976 magnitude 6 centred west of Vancouver Island; it was not reported felt.

The Service installed during 1976, and has continued to operate, a temporary seismograph array near Windsor, Ontario. This array is being used to analyse seismic disturbances in the region and to attempt to establish the origin(s) of earth tremors felt in the Windsor area in recent years.

The Service has agreements with Hydro-Quebec, Société d'énergie de la Baie James and, through a University of British Columbia research agreement, with B.C. Hydro to monitor seismic activity in the vicinity of the Manicouagan, La Grande 2 and Mica damsites, respectively. The purpose of the seismograph operations is to monitor the regions for any seismicity that may be related to resevoir loading, or, in the case of La Grande, pre-loading activity. The induced seismicity at the Manic 3 reservoir, which commenced in the Autumn of 1975, has been monitored since September, 1976 with a 6-element telemetered seismic array. By the Spring of 1977 the activity had decreased to a very low level. An analysis of the results obtained to date from E.P.B. field activities in the Manic 3 region has been completed, resulting in a decision to discontinue the special array monitoring in August, 1977 unless there is a significant renewal of activity.

Special investigations of significant Canadian earthquakes have continued. Reassessment of data available on twentieth century earthquakes in the Charlevoix region of the lower St. Lawrence had indicated that the historical seismicity may be confined to a smaller zone than previously believed. An analysis of four earthquakes in the Byam Martin Channel in the Arctic archipelago has revealed shallow depths and provided some of the first evidence for an understanding of the seismotectonics of this region. A June 1975 magnitude 5.3 Beaufort Sea earthquake, the largest in this region since 1937, is being analysed in detail to provide a better understanding of the nature of the seimicity in this important resource exploration area. A re-evaluation and analysis of available information for the 1946, magnitude 7 Vancouver Island earthquake has led to a revised location and a further understanding of the relationship of this important earthquake to current west coast tectonics. The Pender Island earthquake, which had a focal depth of about 60 km, is also being analysed in the light of recent hypotheses of on-going subduction beneath Georgia Strait and Puget sound.

The Service responds to numerous requests for information on seismic risk from engineers, various government agencies and the general public. Special studies have been undertaken to establish methods of estimating seismic risk at sites of critical structures. The Service has continued its work to develop procedures for establishing seismic risk at nuclear power plant sites in eastern Canada in cooperation with AECB, AECL and provincial power utilities, and as part of a code committee establishing a new standard of seismic design requirements for CANDU nuclear power plants.

Seismological Studies of Earth Structure

The Service studies the dynamic processes, materials and structure of the Earth beneath Canada by a wide variety of techniques, all 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.

Methods and techniques are being evaluated for studying the stress field and stress changes within the Earth's crust. Special emphasis is being placed on methods that may be applicable in regions such as eastern Canada where few earthquake focal mechanisms are available to delineate the stress field.

In August, 1976 the first Canadian experiments were conducted with ocean bottom seismometers when three were deployed off the coast of southwestern British Columbia near the Explorer Ridge, an active seafloor spreading feature. In one configuration the seismometers were used as recorders for a 75 km long reversed refraction profile perpendicular to the Explorer ridge; the data are being analyzed to determine the oceanic crustal structure. In another configuration the seismometers were employed to record earthquake activity. Approximately 1000 earthquakes were detected of which about 100 could be accurately located on and near the spreading centre. The experiment was fortunate in recording a magnitude 4.5 earthquake, located about 3 km from one seismometer. This earthquake is being used as a calibration event for the re-location of other offshore earthquakes using data from the land-based stations.

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. Calibration explosions have been employed to monitor velocity changes that may precede a large earthquake. Between 1974 and the end of 1976, eight calibration explosions were set off in the region, five in an abandoned mine on the north shore and three in 50-metre drill holes on the south shore. These explosions were recorded by up to 15 temporary stations distributed throughout and beyond the active zone. The identification of velocity changes with time requires very precise timing of the arrivals of the seismic signals, and extensive analyses have been undertaken to assess potential timing errors. It is concluded that to the end of 1976 no velocity changes have been detected. It is planned to continue periodic explosions in future years, with the next scheduled for September, 1977 . A seismograph station was installed at the Charlevoix Observatory to continuously monitor low level earthquake activity. On the basis of the first six months of recording, the activity appears to be lower than in recent years.

A seismic refraction survey was conducted on the Beaufort Sea ice during April and May 1976, in conjunction with the AIDJEX program. The data are being analysed to provide an estimate of the structure and of the velocity anisotropy of the oceanic crust. Research on the oceanic crustal structure in the Explorer Ridge area using ocean bottom seismograph refraction data is underway in cooperation with the Atlantic Geoscience Centre and the University of British Columbia. A study of the upper mantle of southern B.C. using surface wave inversion has shown significant low velocity zones in the central and eastern portion of the region. Theoretical studies of the effects of a finely layered crust-mantle transition zone have been applied to the interpretation of a 1975 vibroseis survey in B.C.

A technique that makes use of the properties of interfering P wave arrivals to detect the presence of small triplications in travel-time curves has been used to identify regions of high velocity gradients in the lower mantle at depths of 1250, 2350 and 2700 km.

Geoscience of Nuclear Explosions

The Service is responsible for basic and applied research into the use of seismology; in particular, it carries out research and provides advice to the Department of External Affairs on all matters pertaining to seismological verification of a ban on underground nuclear explosions.

Analyses of a number of seismic events, predominantly underground nuclear explosions, have been made during 1976-77, often in cooperation with seismological research groups in the UK and Sweden. Arrangements have been completed to make the Yellowknife array event detection bulletin available to research groups in the US, UK and Sweden.

In April, 1976 the Conference of the Committee on Disarmament in Geneva established an Ad Hoc Group of scientific experts to consider international cooperative measures to detect and identify seismic events. Officers of the Service are representing Canada in the meetings of this Group.

GEOTHERMAL SERVICE

Permafrost Studies

The Geothermal Service has measured the thermal profiles at over 90 locations in the Arctic Islands, Mackenzie Valley and other northern

regions of Canada, and publishes the measured and calculated equilibrium temperatures of all the wells north of 60°N on an annual basis. Individual wells are logged several times after completion as the rate of decay of the drilling disturbance reveals the physical properties of the surrounding rocks and the thickness of the permafrost. Measurements at 33 locations in the Mackenzie Delta show great variability in the thickness and character of the permafrost there.

In support of environmental-social studies directed at potential northern development, the Service has undertaken thermal studies of the near-surface regime in the Arctic channels using temperature gradiometers developed originally to measure heat flow through the ocean floor. Shallow thermal measurements have also been made along the shorelines of Byam Martin and Little Cornwallis Islands, in eastern Melville Island and in regions of the Keewatin.

Cooperative studies with the GSC which combine seismic techniques and thermal studies of permafrost have extended the observations to the offshore areas of the Beaufort Sea. The high cost of conventional drilling techniques has led to the joint development of a hydraulic jet-drill which for shallow holes is both convenient and economical. The studies undertaken using all of these approaches have shown how closely the distribution pattern of permafrost relates to the combined history of water- and ice-cover.

The thermal data from deep northern wells is also proving of value in outlining possible zones of occurrence of gas hydrates, ice-like combinations of water and natural gas, which currently present a hazard to northern drilling operations but which may in the future be an additional producible source of natural gas.

Geothermal Energy Resource Studies

The Geothermal Service coordinates the research and development activities of the Federal government in the field of geothermal energy. Continued field observations of thermal parameters by the Earth Physics Branch and volcanic features by the Geological Survey of Canada yield information that is essential to the delineation of areas of geothermal potential. Surveys have been performed by Universities and consultants under contract to the Department.

During 1976 a reconnaisance geochemical survey of hot-spring water in the Yukon and adjacent Northwest Territories was undertaken. In the Meager Creek area of southwestern British Columbia several surveys of a possible reservoir area have been undertaken, including detailed geological mapping, age measurement of volcanic rocks, hydrology and magnetotelluric observations.

The geothermal potential of the deep sedimentary basins of Western Canada has been the subject of a second contracted study. Calculations based on the first study showed that the total heat energy contained in hot water in porous formations amounts to about 8×10^{12} barrels of oil equivalent. This water is widely and unevenly distributed and much of it is capable of production through deep wells, although conditions at any individual location may not be known. Problems may occur due to pumping requirements from great depths and due to very high salinities in some areas. Any water produced must be used close to its source, since transmission of energy in this form is expensive. Exploitation must be by direct use since temperature is not high enough for economic electrical generation. This energy source is not renewable, and the thickness and permeability of the reservoir rocks will impose limits on

the duration of exploitation. The University of Regina has expressed an interest in this source of energy for space heating of a large building, and a feasibility study will be carried out at the University in the coming year.

Geothermal Studies of Deep Earth Structure

The third catalogue of world heat flow data has been published by the Earth Physics Branch. This work, a contribution to the activities of the International Heat Flow Commission, was a combination of the oceanic data, compiled elsewhere, with the continental data, which were recompiled in the Branch. The publication lists a total of 5417 measurements from all parts of the globe.

A study of the thermal nature of the crust beneath the Maritime Provinces, in cooperation with Dalhousie University, has shown that temperature gradients and heat flow are high in areas of granitic intrusion and low in the sedimentary terrain of the Cumberland Basin. Although data are sparse and limited to a thin surface veneer, the results suggest that the Cumberland Basin does not have the same potential for geothermal exploitation that the Western Canadian Basin has.

The heat generated by radioactivity in rocks of the Coast Range Complex and other parts of British Columbia has been examined. Results show that the heat generation in the Coast Range Complex is low compared with southeastern British Columbia. This is in agreement with observed heat flow and suggests that coastal temperature is correspondingly higher. Recent volcanic activity has penetrated the Coast Range and thermal patterns are probably complex. The regional assessment of geothermal resources depends on a thorough understanding of the nature of the crust beneath the western mountain belt.

The history and nature of the crust, as revealed by geothermal and other geophysical research, yield an understanding of the distribution and origin of mineral resources including geothermal energy and ore deposits. The analysis of thermal events in the north yields an understanding of the presence of permafrost and the probable result of man-made disturbances. The science of geothermics has proved to be a discipline with considerable value in the field of applied research.

DIVISION OF GEOMAGNETISM

P.H. SERSON, Director

The Division of Geomagnetism is responsible for the Geomagnetic Service of Canada, providing up-to-date information on the magnetic field of the earth to users in many fields - for example, 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 maps and manuals published by other federal, provincial and international agencies. It publishes every 5 years revised magnetic charts of Canada and the adjacent ocean areas. The Geomagnetic Service provides data in analog and digital form on the daily variation of the magnetic field and on magnetic storms. It issues regular forecasts of magnetic activity, which are now broadcast twice per week by the CBC northern radio network.

The Geomagnetic Service maintains the data base necessary for the above functions by carrying out systematic surveys, on the ground and in the air, and by operating the Canadian Magnetic Observatory Network,

consisting of 11 fixed observatories which continuously record the intensity and direction of the varying magnetic field.

The Division research program includes paleomagnetism, interpretation of aeromagnetic anomalies, electromagnetic induction in the earth and studies of geomagnetic time variations and pulsations. Canada is particularly well suited to these aspects of research in 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 sub-auroral 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 2000 million years. Magnetic and magnetotelluric methods are being used to study and locate geothermal resources in western Canada. Their usefulness as a tool for earthquake prediction is being assessed in a seismically active region on the north shore of the St. Lawrence River.

DIVISION OF GEOMAGNETISM

Magnetic Observatories

Eleven magnetic observatories operated throughout the year 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 Canada. Edited data from the variation station at Whiteshell, Manitoba is also available upon request.

At all of the above stations except Mould Bay, an Automatic Magnetic Observatory System (AMOS) records the northward, eastward and vertically downward components of the magnetic field plus 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. Daily checks are made of the operation of the AMOS installations by telephone from Ottawa.

The basic prototype of an improved Automatic Magnetic Observatory System has been built and tested. The new version is based on a microprocessor which is now programmed to duplicate the functions of existing AMOS, but with further development the system will be self-checking for instrumental integrity and data consistency. It will also compute mean hourly values and hourly ranges, and store them together with status information until interrogated by telephone.

The AMOS at St. John's, Nfld. was moved to a new building, away from encroaching roadways and vehicle parking. A new AMOS building was also put into service at Victoria.

The magnetic observatories at Meanook, Ottawa and Victoria have been equipped with newly-developed photographic recording variometers which do not require daily servicing but will operate unattended for weeks if necessary.

Magnetic Surveys

A three-component airborne magnetometer survey of Quebec, the Atlantic Provinces and the Atlantic continental shelf was made during the months of September and October 1976 at an altitude of 3 to 5 km. The flight lines ran approximately north-south with a line spacing of about 75 km, for a total of 85,400 line-kilometers. This survey completes the

present phase of high-level airborne vector coverage of Canada.

As part of a continuing multi-disciplinary survey of Hudson Bay in cooperation with MOT, a total magnetic field survey was carried out aboard the CCGS Narwhal. Approximately 12,800 line-kilometres were completed between July 17 and August 26, 1976.

Management of Geomagnetic Data Base

Observatory Data

Final magnetic tapes storing geomagnetic data for 1975 and about one-half of 1976 were completed for all observatories. The tapes contained one minute values of all recorded components (except for Mould Bay), mean hourly values, hourly ranges and summary tables. Observatory yearbooks for 1973 and 1974 were submitted for publication. Microfilm copies of magnetograms for all observatories are sent monthly to World Data Center A in Boulder, Colorado, with edited versions of the digital magnetic tapes.

Forecasts of Geomagnetic Activity

As a service to geophysical exploration companies, electrical power companies and pipeline companies, the Ottawa Magnetic Observatory has continued to issue two types of forecasts of geomagnetic activity:

(a) a 27-day forecast issued at 3 to 4 week intervals and distributed by mail, and

(b) a 72-hour forecast, prepared twice a week and available by telephone.

The CBC northern radio network of 46 stations is continuing to broadcast the 72-hour forecast twice a week.

Magnetic Charts

Tests were carried out on the mathematical model used to derive the 1975 magnetic charts of Canada. The model is in the form of a 6th order polynomial function of latitude and longitude, and a cubic function of time. Data from North American magnetic observatories were used to test the predictive capabilities of the model. These comparisons show a significant decrease in accuracy of the model over a few years. A study of other predictive methods indicates that only graphical techniques are sensitive to sudden changes in secular variation.

It was shown that the secular variation pattern in Canada is greatly influenced by four isoporic foci, or centres of rapid change. An examination of the movements of these foci indicates that the horizontal component will continue to increase rapidly in eastern Canada; the declination will change more rapidly over most of the country, especially in eastern Canada; and the vertical component will begin to decrease in parts of northern Canada and will decrease more rapidly in south-eastern Canada.

A comparison of the International Geomagnetic Reference Field (1975) with annual mean values extrapolated to 1977 for 130 magnetic observatories indicates many large secular variation departures over the world. Departures in the vertical component were especially prominent, exceeding 40 nT per year over parts of North America. These large time-term errors, coupled with the known main field errors, provide a compelling argument for adopting a completely new model for the international reference field.

Paleomagnetic data

The listing and appraisal of world-wide paleomagnetic data is now complete and has been published in five issues of the Geomagnetic Series: Issue 1, Results up to 1971; Issue 2, Precambrian results 1957-1974; Issue 3, Palaeozoic results; Issue 4, Mesozoic results and results from seamounts; Issue 5, Cenozoic results.

Geomagnetic Studies of Earth Structure

Magnetic Anomalies

A study of broad-scale magnetic anomalies, rock magnetic properties and geology in the southern Coast Mountains of British Columbia has continued jointly with personnel of GSC, Vancouver. Although a long intense magnetic anomaly correlates with high magnetizations found at the surface, the evidence shows that there is a deeper more magnetic zone in the crust. The cause of this highly magnetic region has been attributed to subduction, since Cretaceous time, of oceanic crust beneath Vancouver Island and the mainland. Partial melting of the downgoing slab under hydrous conditions, with subsequent recrystallization of material advected upward, results in increased magnetite content in the crust near the volcanic front.

The joint project with personnel of Goddard Space Flight Centre NASA has continued. A revised airborne data set was upward continued to 500 km altitude, which is the mean altitude for the satellite data set. Good agreement exists between magnetic anomalies seen in these airborne data and anomalies seen in the revised satellite data set, over western Canada and Arctic regions, except in a small area still under investigation. This project has been instrumental in encouraging international plans for worldwide magnetic surveys by satellite, beginning in 1980.

Detailed model interpretations of the prominent magnetic anomaly at the centre of the Manicouagan Impact Structure, Quebec, indicate a body approximately 8 x 12 km in lateral extent, from near surface to about 3 km depth. The magnetization direction agrees with paleomagnetic directions obtained previously from melt rocks in the crater. Shock remanent magnetization at the time of impact is a likely explanation for the origin of the anomaly.

Paleomagnetism

Several Precambrian and Archean rock units have been studied during the year. Results that have been published or submitted for publication are from the following rock units: The Abitibi dikes, the Matachewan dikes, the Kamiskotia complex, the Dundonald sill, the Rapitan Group, the Michikamau Intrusion, rocks from the Central Labrador Trough, the Harp Lake Anorthositic Complex, the Seton Formation, the Douglas Peninsula Formation, the Takiyuak Formation, the Pearson Formation and the Jacobsville sandstones.

The Archean results have been used to sketch an Archean polar path (Track 6). Aphebian results indicate that an event of folding and subsequent remagnetization may have affected a wide area of Quebec to Minnesota prior to intrusion of the Nipissing diabase (2,150 Ma). Results from these different studies indicate that Laurentia has remained intact for at least the last 2.2 Ba. The Jacobsville sandstones and Rapitan Group results have led to a reinterpretation of the Hadrynian

Polar Track. These data also support the hypothesis of an integral single plate unit for Laurentia and Grenvillia.

Several studies of Paleozoic rocks have been completed. A paper on the occurrence of a transcurrent motion in the Northern Appalachians and Caledonides during the Lower Paleozoic has been published. A study of the Botwood Group and Mount Peyton Batholith, and a review of Lower Paleozoic paleomagnetic data have been submitted. A paper on the Lower Ordovician Connemara Suite in Western Ireland has also been submitted, and other rock units are under investigation.

Results of an extensive study of the magnetization of the red sandstones of Minudie Point, N.S., are in press. This investigation has enabled the more precise determination of the stratigraphic position of the Carboniferous reference horizon. This reference point can be used with confidence in the study of the tectonic history of the ancient Carboniferous basin of eastern Canada. Moreover, its determination in other Carboniferous sequences will provide a simple and effective basis for world-wide correlations.

Research has continued on the evolution of the Arctic Ocean as part of a Branch-wide study of Arctic geophysics.

Fifteen global maps summarizing the drift of the major continental blocks since the Devonian are in press. These maps indicate that, at the end of the Paleozoic, a redistribution of the major continents occurred without the formation of a new ocean. This episode of continental drift appears to coincide with the world-wide extinctions of species and the development of oil-rich structures around the North Atlantic.

Much effort has been directed toward the improvement of the existing magnetic cleaning techniques and the finding of new ones, and new techniques and instrumentation have been developed. Chemical leaching is proving to be the most efficacious treatment for the separation of the different phases of magnetization of sediments.

Electromagnetic Induction

The magnetotelluric method is being used to investigate earth resistivity changes which might be associated with the build-up of stress in crustal layers prior to the onset of an earthquake. For this purpose magnetotelluric fields have been monitored for 2 years near the centre of seismicity in a tectonically active region 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, with changes of more than 30% in the impedance tensor occurring over periods of a few months. 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 so far to develop a clear association between seismic activity and resistivity changes. Seasonal changes in the temperature and salinity of the nearby St. Lawrence River may be an important factor. Much less variation in impedance was observed at similar recording stations located less than 100 km to the west of La Malbaie and in the Manicouagan region 265 km to the northeast. Magnetotelluric recording is continuing in an effort to assess the usefulness of the method as a means of earthquake prediction.

Study of the large crustal or upper mantle conductivity anomaly beneath the western Arctic Islands (the Mould Bay anomaly) continued in

the spring of 1976 when a profile of 11 three-component fluxgate magnetometers was operated for 1 month on a 500 km line extending from north-central Banks Island to south-central Victoria Island. The magnetic components were digitally recorded on cassettes. The Polar Continental Shelf Project provided logistical support and air transport for establishment and removal of the stations.

The Mineral Exploration Research Institute, under contract, completed an audio magnetotelluric reconnaissance survey at three locations in the Lillooet Valley. Though geothermal effects at shallow depths were not found, many of the recording sites showed strong anisotropy with low resistivity in the north-south direction and high resistivity east-west. The anisotropy may be caused by fracture zones associated with geologically recent rifting and volcanism. A highly conducting layer was found at a depth of 20 km suggesting the existence of high temperatures at this depth.

Geomagnetic variation stations were temporarily established along lines across western British Columbia and Washington State in cooperation with the University of Washington. Preliminary interpretation indicates high electrical conductivity at depth under all of the region and an anomaly probably associated with the Cascade line of volcanics.

An ocean-bottom magnetometer was designed to measure and record variations in the geomagnetic vector on the sea floor for induction studies west of Vancouver Island in active tectonic areas. Construction of the prototype has begun.

Geomagnetic Disturbances

Bays and Pulsations

Pulsations in the period range 150-600 seconds (Pc5) recorded in 1967 at Resolute Bay, Baker Lake, Fort Churchill, Great Whale River, Meanook, Victoria and Agincourt were further analysed to investigate the movement of the cleft region. Eleven years (1962-1972) of Pc5 scaled hourly values were analysed to study the solar cycle influence on this group of pulsations. The annual and semi-annual variation and a previously suspected 27-day recurrence tendency have been clearly demonstrated.

The quiet-time Pc5 event (designated Spacequake) of March 18, 1974 was studied in detail and then long term characteristics of these rare events were investigated by using nearly 45 years of data from Resolute Bay, Fort Churchill, Great Whale River and Meanook. Such events seem to originate close to the magnetopause possibly by Kelvin-Helmholtz instability related to internal convection of the magnetosphere.

Single-component induction magnetometers were put into operation at Ottawa and Resolute Bay to record short-period pulsations north and south of the auroral zone while similar measurements are being recorded in the central part, near Churchill, by the University of Alberta.

Solar and Lunar Variations

The development of the Chapman-Miller program, which computes solar and lunar harmonic coefficients associated with geomagnetic variations, was completed and the documentation prepared. The program is capable of handling large volumes of magnetic observatory data and regrouping them according to the constraints imposed by a particular problem or study.

Results are presented as harmonic coefficients and in various graphical representations.

Auroral and Cleft Region Current Systems

Models of the electric current system in the magnetospheric cleft were constructed for Los Alamos Scientific Laboratories rocket campaigns. The Black Brant rockets were launched from Cape Parry, N.W.T. on the 25th and 28th of November, 1975. The cleft is the day-side extension of the auroral oval. Cleft region currents were found to be similar to auroral currents but flowing at an altitude of 200 km instead of the usual 100 km of auroral and diurnal current systems. Intense field-aligned currents were flowing outward above the arcs and downward at the edges of the cleft region.

International Magnetospheric Study

The Geomagnetic Service is operating a north-south line of 8 magnetic variation stations as a contribution to the International Magnetospheric Study (IMS), 1976-1979, and to support IMS auroral and rocket compaigns. These variation stations are located at Island Lake, Thompson, Ft. Severn, Gillam, Back, Eskimo Point, Rankin Inlet and Alert. Permanent stations also along the line are Whiteshell, Fort Churchill, Baker Lake and Resolute. All the temporary variation stations except Alert were upgraded by October, 1976 with newly developed low power digital tape recorders. The 3 components of the magnetic field are sampled and recorded every 10 seconds. Edited copies of the tapes and auxiliary analogue records are sent to the World Data Center at Boulder, Colorado.

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 which contribute to an understanding of both local geologic features and regional geologic frameworks in Canada. The Geodynamics Service is responsible for studies of the earth's rotation, polar motion, earth tides and for investigations of crustal strain and tilt related to tectonic movements, ground water levels and earthquake prediction.

During 1976-77, major offshore gravity surveys were carried out off Vancouver Island, in Hudson Bay, in the Beaufort Sea, and in Amundsen Gulf. Surveys done under contract were completed in offshore areas of British Columbia, in Hudson Bay east of the Belcher Islands, and over much of Nova Scotia. The Division introduced an open file system for the timely release of new gravity survey data. Three open files were released during the year. The Gravity Service has a substantial role as an adviser to industry, the provinces, and internationally in matters related to all aspects of gravity surveys and particularly gravity standards. The maintenance service for the International Gravity Standardization Net (IGSN71) which the division was asked to undertake by the International Association of Geodesy, is now in operation. A compilation and adjustment of gravity control stations in Latin America

was also completed during the year. A final report of this work will be presented at the General Assembly of the Pan American Institute of Geography and History at Quito, Ecuador in August 1977.

Recognition of the common features of gravity anomalies over structural boundaries in the Precambrian Shield and the possible implications of these results for a better understanding of the shield's formation has helped to focus attention on the role of plate tectonics in the Precambrian. A review of available geophysical and geological evidence along the continental margin of British Columbia south of 51°N suggests that the most reasonable explanation of contemporary tectonics in that area is in terms of continuing subduction of oceanic lithosphere beneath Vancouver Island. During 1976 important new insights into the mechanics of large hypervelocity impact sites were obtained by comparing data from Canadian craters with data from underground nuclear explosions. During the year the Geodynamics Service released the results of a two year experiment to prove the technique of nanogravimetry. A new type of extremely sensitive gravity meter was used to detect seasonal fluctuations of the water table. The results demonstrate that nanogravimetry may be applied to determine crustal movements which could be the precursors of earthquakes.

GRAVITY SERVICE

Gravity Mapping

In 1976-77, approximately 15,000 line kilometres of dynamic gravity data were observed during two shipborne surveys; an additional 4600 static gravity measurements were observed on land and on ice-covered coastal regions. Shipborne surveys were carried out in cooperation with the Canadian Hydrographic Service off the northwestern shores of Vancouver Island to a distance of 100 km and in Hudson Bay. The Hudson Bay survey was designed to interline the 45 km track spacing completed in 1975. Using helicopter support, gravity and bathymetric data were collected from the ice-covered surfaces of Amundsen Gulf and the Beaufort Sea. This survey was also a cooperative effort with the Canadian Hydrographic Service and was supported by the Polar Continental Shelf Project of EMR. Reconnaissance survey data in the general area of the Beaufort Sea and Amundsen Gulf is now complete.

The Division's policy of contracting surveys to industry was extended in 1976-77. Three surveys were done under contract. An underwater gravity survey, in which gravity readings were made on the sea floor by lowering a specially adapted gravity meter, was completed off the west coast of Vancouver Island and the Queen Charlotte Islands in British Columbia. A second survey was commenced over the ice-covered surface of Hudson Bay north and east of the Belcher Islands. A conventional helicopter-supported land survey covering much of Nova Scotia was also undertaken. Average station spacing in these surveys was 6 km.

Systems Maintenance and Updating

Efforts throughout the year have been concentrated on refining the reduction and editing systems for field observations in order to reduce the time interval between the gathering and the dissemination of data. Significant improvements in software, particularly in relation to processing offshore gravity data, have been made in the past year. Introduction of the open file system also contributed to a more timely release of data.

Systems Development

Research in both marine and aerial dynamic gravimetry continued. Analysis of data collected using the precise gyro installed in 1975 revealed a hitherto undiscovered platform azimuth oscillation in marine data and large azimuth wanderings in aerial applications. Consequently the assumption that platform azimuth errors are small was proven invalid and techniques were developed to determine the platform orientation from azimuth gyro data. Previously analysed marine and aerial data are being re-evaluated in the light of this discovery.

Map Production

Three open files comprising gravity anomaly maps and related digital files were released in 1976 as follows; 76-1 Queen Charlotte Sound (2700 observations), 76-2 La Perouse Bank (2100 observations), and 76-3 James Bay (2300 observations).

Gravity Standards and Gravity Data Base

The systematic inspection and updating of control stations of the National Gravity Net was continued by contract in northern Ontario and southern Quebec. A total of 369 stations was visited and 88 were replaced. Updated gravity values and base station descriptions for this area are now available on request.

All necessary modifications to the data base required to implement the maintenance service for the International Gravity Standardization Net 1971 (IGSN71) have now been made. Information for updating some 800 IGSN71 station descriptions has now been received from 47 countries and compilation of new descriptions, to be distributed through the International Gravimetric Bureau in Paris, is now underway.

Compilation and adjustment of a 1000 station reference network spanning 21 countries in Latin America is now essentially complete. During the next three years, the data base and the expertise necessary to sustain the on-going maintenance program will be transferred to a Latin American agency. The Brazilian national net, not presently included in the Latin American Gravity Standardization Network, is currently being observed by Brazilian government agencies. The Gravity Service has assisted in the planning of this net and has provided six weeks of training to a Brazilian geodesist.

Advice and assistance was also provided to the Ontario Ministry of Natural Resources in the processing of data from a gravity survey in the Red Lake area. Similar assistance, including the production of a 1:250,000 gravity map of the Notre Dame Bay area was given to Memorial University, Newfoundland.

The National Gravity Data Base incorporates gravity and related data obtained by departmental surveys, or contributed by provincial government agencies, universities and industry. In response to 125 requests received over the past year from exploration companies, government agencies and universities the Gravity Data Centre retrieved and distributed 104 million characters of information, mostly in the form of magnetic tapes. About 15% of the requests required preparation of digital anomaly maps. In addition, 1040 descriptions for reference stations were requested. In support of in-house field and research programs an additional 232 requests were processed involving the retrieval of some 54 million characters of information, 1.5 million of which were also plotted.

Gravity Studies of Earth Structure

Studies of gravity anomalies, usually in conjunction with other geophysical and geological data, provide information about the size, shape and depth of bodies with contrasting densities below the earth's surface. Short wavelength anomalies usually have their sources within the crust; long wavelength anomalies may result from deeper density discontinuities in the mantle and even at the core-mantle boundary.

As a contribution to a branch-wide study of geophysical data available in the Arctic the Division undertook the compilation of free-air and bathymetric maps north of 60°N at a scale of 1:7,500,000. This work has led to significant improvements over previously published maps of the region. The compilation of Phanerozoic vertical motion data from Arctic regions is virtually complete. Interpretations of these and other compilations along with the maps themselves will be published in the near future. In studies of other offshore regions, the evidence for subduction processes during the last 10 million years off Vancouver Island was reviewed and calculations have been made to determine the extent and thickness of the lithospheric slab that has been subducted; in Amundsen Gulf, a joint study with the Geological Survey of Canada of gravity and magnetic anomalies confirmed geological estimates of the thickness of sedimentary strata. The surveys also revealed a large local anomaly in the Gulf similar to the anomaly at Darnley Bay (the largest local gravity anomaly in Canada). The investigations suggest that a basic or ultrabasic intrusive body is the source of this unusual anomaly.

Studies of gravity anomalies at several structural boundaries in the Shield suggest that density discontinuities penetrate the entire crust in these localities. These discontinuities have been interpreted as sutures between collided continental fragments suggesting that plate tectonic processes have operated during formation of the Shield in Precambrian time. If this hypothesis is correct, the ancient plate boundaries may be compared with modern examples where new concepts of metallogeny are currently evolving. Local investigations in the Shield of the Moran anorthosite and Gow Lake and Manicouagan impact crater sites were completed.

A continuing study of global gravity and magnetic anomalies suggests that there may be a fairly close relationship between fluid motions at the surface of the core and lithospheric plate motions at the surface of the earth. Research in physical geodesy continued in 1976-77 with development of a computer program to facilitate the representation of the gravity field over portions of the globe by spherical harmonics up to order 200 - a limit set only by computer memory size.

As part of the investigations into the physical and chemical state of rocks subjected to high pressures and temperatures, studies of the mechanism of crustal melting at the Manicouagan structure, Quebec, were completed in collaboration with NASA scientists. A study of the rate of shock wave decay, as recorded in rocks at several Canadian impact sites, was also completed and the results incorporated into theoretical models based on comparisons between meteorite impact and nuclear explosion sites. The Manicouagan results were also applied to lunar studies directed at determining the composition of the lunar crust at major lunar basins.

Studies continued in collaboration with other branches on the suitability of rocks in the Canadian Shield for storage of nuclear wastes. These included an assessment of sites for thermal experiments to

be carried out by CANMET and an evaluation of geophysical techniques to be used in site selection surveys.

GEODYNAMICS SERVICE

Generation and Management of Geodynamics Data

Polar Motion

Polar motion and earth rotation have been monitored from the Polar Motion Observatories near Ottawa and Calgary using astronomic (P.Z.T.) and satellite Doppler techniques. Astronomic data are transmitted regularly to the international time (B.I.H.) and polar motion (I.P.M.S.) services which are responsible for obtaining the combined global solution. Satellite Doppler observations are transmitted daily and processed on a routine basis by the DMATC Polar Monitoring Service together with data from a world-wide satellite tracking network. In 1976 the routine operations and data communication of the Ottawa Tranet satellite tracking station have been fully automated and the section moved to the Shirley's Bay site alongside the astronomical instrument. The Canadian PZT's have received the two highest combined weights for time and latitude observations among 75 instruments from around the world contributing to the B.I.H. system in 1976. An analysis of simultaneous satellite and astronomical observations show approximately the same dispersion of the mean daily coordinates. The satellite results do not indicate apparent seasonal variations which are characteristic for the astronomical results: however, the latter support the satellite system by providing the necessary information on the earth's rate of rotation.

Detailed comparison and analysis of polar motion as determined by the astronomical and satellite techniques at co-located stations is necessary for understanding their differences and analyzing error sources and the related effects.

Earth Tides

Earth tide data were collected at Glen Almond, P.Q., Charlevoix, P.Q., and Fredericton, N.B. during 1976 in support of various research projects. At Glen Almond, P.Q. improvements were made to the automatic calibration system of the hydrostatic tiltmeter and a new digital recording system went into operation. Recording of the gravity tides was commenced at Fredericton, N.B. during the latter part of the year to provide data on the gravity tide anomaly thought to be due to anomalous ocean tides in the western Atlantic. Strain and tilt tides were recorded at Charlevoix, P.Q. in an experiment to monitor the elastic properties of the crust in a seismically active area. Where these data meet certain minimum quality standards they are transmitted to the Commission Permanente des Marees Terrestres, Association International de Geodesie in Brussels, which acts as a collecting and distributing centre for world wide earth tide data.

Dynamics of the Earth

Precise gravity networks for the measurement of crustal deformation were established in 1976: (1) at the Manic 3 dam in Quebec where seismicity was induced by the filling of the reservoir, (2) in the Charlevoix region of Quebec where there is a concentration of natural seismicity, (3) along the first order level line from Quebec City to Laurentide Park where there is anomalous vertical crustal movement and (4) across Vancouver Island where there have been large earthquakes in

the past. The network at Manic 3 consisted of eleven stations and one hundred and fifty ties made with each of two LaCoste and Romberg model D gravimeters. This survey marks the first time that a precise gravity network has been established by helicopter using these instruments. At Charlevoix a new fifteen station network was established by road, involving over two hundred gravity ties made with each of two instruments. This new network replaces an older one established in 1974. The precise gravity profile from south of Quebec City to Laurentide Park was established to provide a basis for a long term study of gravitational effects associated with the vertical movements there. Two profiles were established across Vancouver Island consisting of thirteen and nine stations each and following existing and proposed special order level lines.

Over the past few years, techniques for the measurement and analysis of changes in tilt, strain and gravity have been under development at the Earth Physics Branch for the study of earth tides. These techniques are now being applied to the study of crustal movements associated with earthquakes. Strain and tilt data recorded at the Charlevoix Observatory near La Malbaie, P.Q. are now being analysed routinely on a month to month basis. A quartz rod strainmeter and an invar wire strainmeter are operating in parallel in the vault, as well as three mercury-level tilt meters. All instruments are operating at earth tide sensitivity and good tidal records have been obtained for analysis for possible changes in tidal amplitudes. Permanent and simultaneous offsets in both strain and tilt have been identified and these are being studied with respect to local seismicity. The variations in crustal dimensions are being studied in conjunction with continuous measurements of tidal gravity, resistivity, seismic velocity, changes in levels and gravity networks.

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

Analysis of laser ranging data to the GEOS-3 satellite has continued during the year with the objective of determining the feasibility of sensing the tidal displacements of the earth's surface. Results have shown the the dynamic force model for the satellite is the limiting factor in the determination of real station movements when a single laser station is used to define the reference arc. Apparent station movements of 5 to 10 meters are seen due to the inadequacies of the existing model.

Gravity, magnetic field, ocean depth and ocean and ice tilt measurements were made throughout the 1976-77 period from a floe station in the Beaufort Sea. During an unusually calm 20-day period in February, when the ice floe remained stationary, the gravimeter records clearly showed the variations due to the ocean and earth tides. From these records it has been possible to determine the amplitude and phase of the three main ocean tide constituents in that part of the Beaufort Sea. Ocean tilt measurements showed fluctuations of the slope of the ocean surface in the 15 microradian range while on the average the ocean tilted down to the NW by about 10 microradians. Ice tilt measurements showed that short period tilt changes (30 microradians) are related to the drift velocity of the ice, whereas long period changes (100 microradians) are due to the shifting of the snow load.

Gravitational, inertial and toroidal oscillations of the outer core are being studied for earth models with a uniformly stable, neutral and unstable outer core in an effort to determine the structure of the outer core of the earth. The particular case of the fundamental toroidal core oscillation, which gives rise to the "nearly diurnal wobble", was studied in detail. The present results show that the internationally adopted nutation constant of 9".210 is incompatible with the theoretical amplitude of 9".1966. This result is significant for the modelling of the polar motion data collected at the Earth Physics Branch and at other stations throughout the world.

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