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CANADIAN NATIONAL REPORT ON GEOMAGNETISM AND AERONOMY

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Foreword

This report has been prepared on behalf of the subcommittee on Geomagnetism (Chairman: P. H. Serson) and the subcommittee on Aeronomy (Chairman: P. A. Forsyth) of the Associate Committee on Geodesy and Geophysics. It has been compiled from material submitted by university departments and government institutions, and provides a summary of activity in geomagnetism and aeronomy since the last national reports were issued in the spring of 1960. The work of commercial companies in exploration and interpretation is not reported. Annual reports on geomagnetism and aeronomy have appeared in the Canadian Geophysical Bulletin (Garland, 1960, 1961, 1962) published by the National Research Council.

Part I. Geomagnetism

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1. Geomagnetic Surveys

1.1. Ground Surveys of the Dominion Observatory

During the field seasons of 1960, 1961, and 1962 about fifty Dominion Observatory repeat stations and many additional locations were occupied for observations of declination, dip, and total intensity. These data are intended primarily for estimation and mapping of secular change.

The Observatory also conducted a special magnetic survey in the vicinity of the north magnetic dip pole in 1962 to determine its present position and rate of movement. Measurements of direction and intensity were made at six locations within 100 miles of the pole. Corrections for geomagnetic time variations were based on the records of Resolute Bay Magnetic Observatory. A preliminary estimate of the pole position for epoch 1962.5 is 75.1°N lat., 100.8°W long. (near the southwest corner of Bathurst Island).

Several local surveys have been completed to provide declination information for navigation and to study geological formations or other areas of special interest.

1.2. Airborne Surveys

The Dominion Observatory's three-component airborne magnetometer surveys of 1960 and 1961 are shown in Figures 1 and 2. A total of nearly 100,000 line miles was flown. The altitude of the observations was generally 10,000 feet.

The Geological Survey of Canada continued its low-level total-intensity surveys, and covered about 115,000 line miles in 1960 and 1961. The areas now surveyed are shown in Figure 3.

A new program to cover the Canadian Precambrian Shield with total-intensity aeromagnetic surveys was put forth by the Geological Survey in 1960 (Figure 3). In this plan both federal and provincial governments contribute to the cost. Flight lines are spaced ½ mile apart, and the average terrain clearance is 1,000 feet. The 1962 surveys included about 30,000 line miles over the Polar Continental Shelf in the Arctic, which are not shown on the map.

1.3. Sea Magnetometer Surveys

Total-intensity surveys were made at sea by the Geological Survey in cooperation with the Canadian Hydrographic Service and the Institute of Oceanographic Research in 1960, 1961, and 1962 (Figure 3). At the present time, a total of 50,000 line miles has been surveyed off the eastern continental shelf of Canada by hydrographic ships equipped with proton precession magnetometers.

A preliminary proton magnetometer survey of Lake Huron was made in 1962 by the University of Western Ontario.

2. Magnetic Charts and Compilation by the Dominion Observatory

An isogonic map at a scale of 100 miles to the inch depicting lines of equal magnetic declination and annual change for Canada, epoch 1960.0, has been published (Dawson, 1960a).

A magnetic declination chart of the Canadian Arctic has been compiled for the Canadian Hydrographic Service, and published (Dawson, 1960b).

To cope with the enormous amount of three-component aeromagnetic data being produced, the routine computations in chart compilation are now done on an IBM computer. Aeromagnetic data from 1953 to 1961 inclusive are entered on punched cards, each card containing position coordinates, G.M.T., altitude, three observed components (D, H,Z), and four computed components (X,Y,F,I). The component values represent 5-minute averages along the flight line. A machine program which sorts

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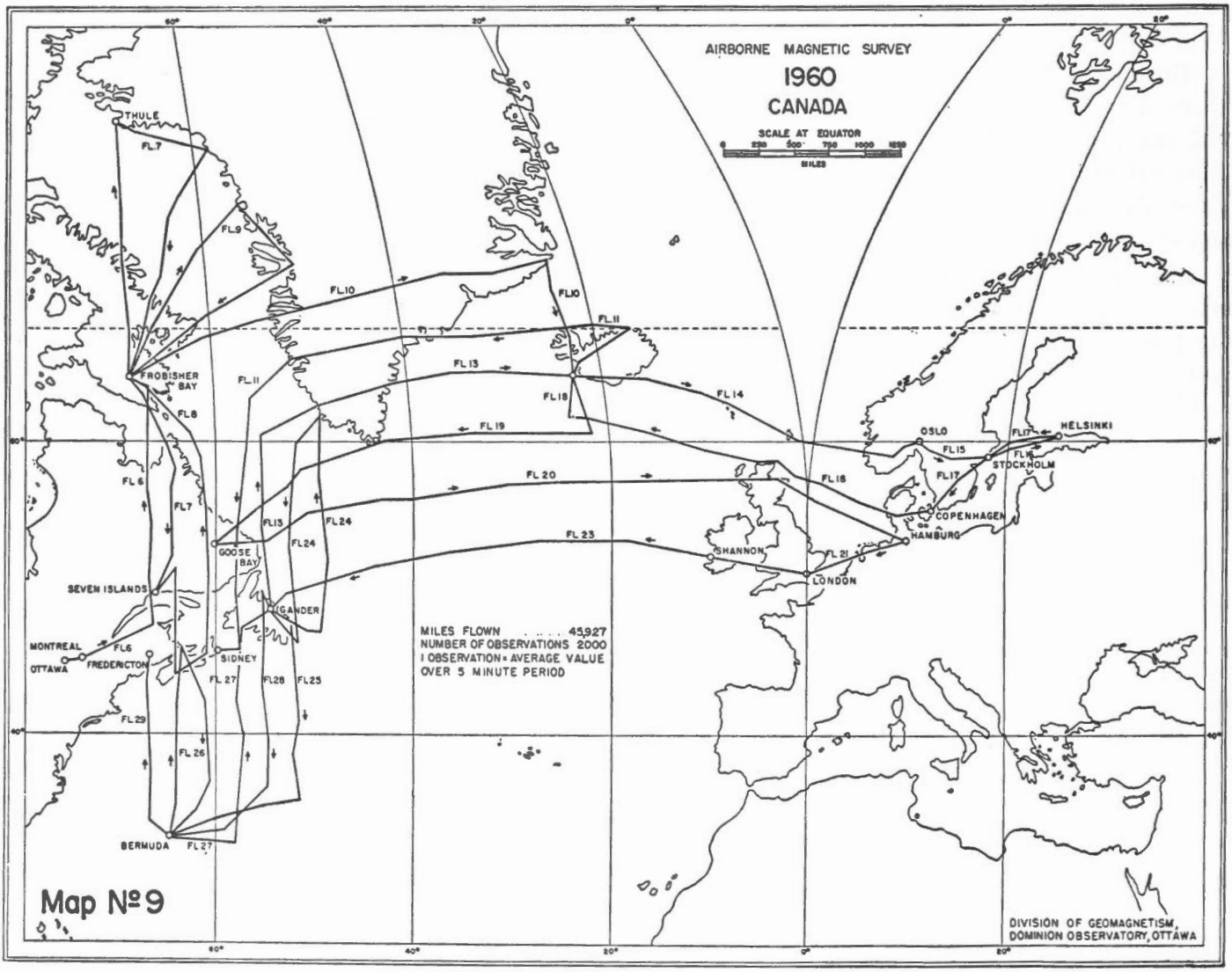

FIGURE 1. Three-component aeromagnetic surveys in 1960.

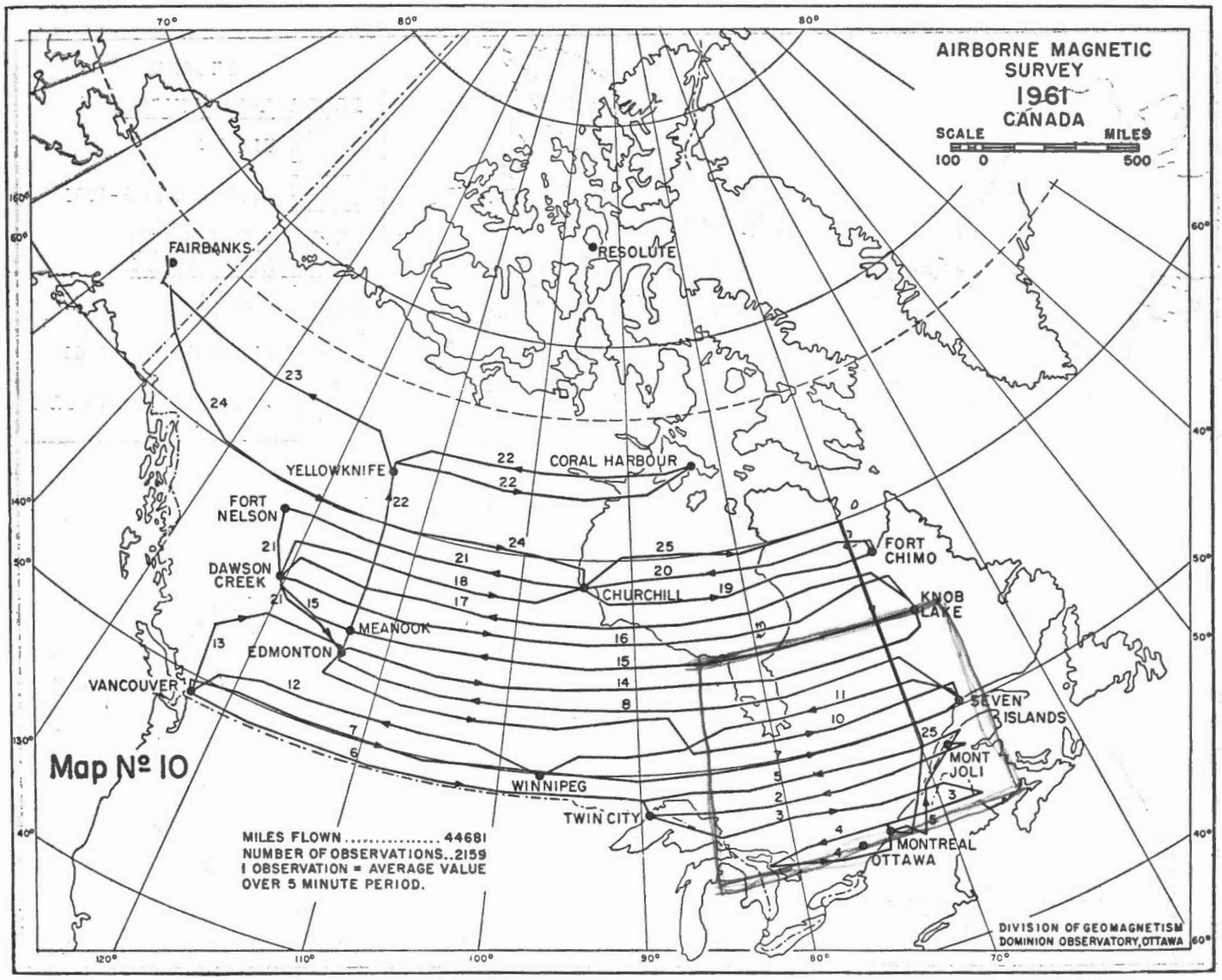

FIGURE 2. Three-component aeromagnetic surveys in 1961.

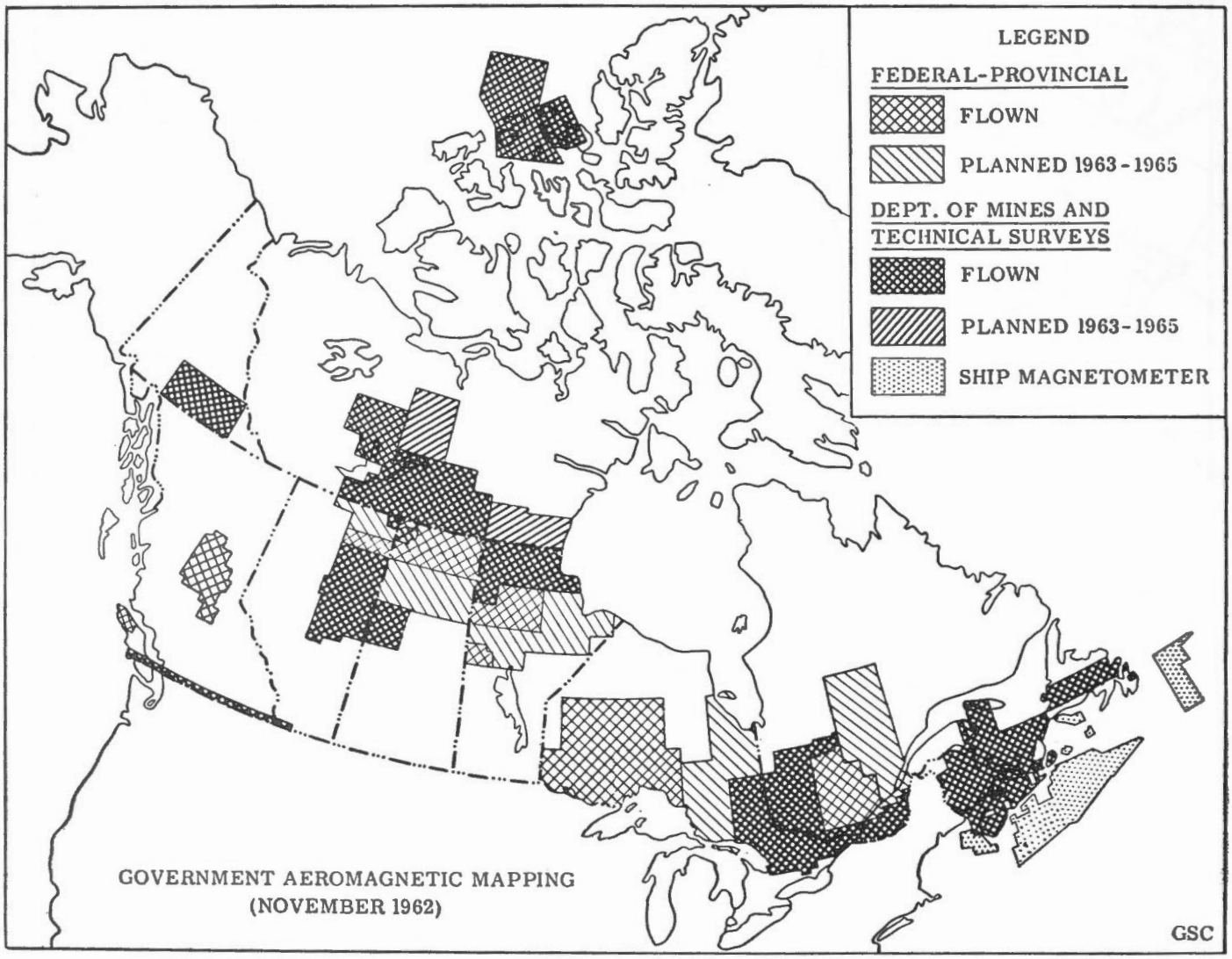

FIGURE 3. Low-level total intensity surveys.

the observations, reduces them to epoch by applying secular change corrections, and smooths them for mapping, has been devised and tested.

3. Magnetic Observatories

The five observatories at Agincourt, Meanook, Victoria, Baker Lake, and Resolute Bay were in continuous operation. In addition, three-component standard-run photographic variometers were operated at Churchill by the Defence Research Board. Two new Arctic observatories were established by the Dominion Observatory in the latter part of 1961. These are at Alert on the northern end of Ellesmere Island (82.5°N, 62.5°W) and Mould Bay on Prince Patrick Island (76.2°N, 119.4°W).

Magnetic observatory results during the International Geophysical Years, 1957 and 1958, have been published for Agincourt, Victoria, Yellowknife, Baker Lake, Resolute Bay, and Churchill. Other observatory publications include the Victoria results for 1959 and 1960, Resolute Bay for 1959, Agincourt and Meanook for 1938-39, and Agincourt for 1955-56. Q indices for selected days during the IGY at Resolute Bay, Baker Lake, and Yellowknife, have also been published. These publications are listed in the bibliography.

The disturbance indices, K, are supplied to I.A.G.A. Committee No. 9 on a routine basis for Agincourt, Meanook and Victoria. Mean annual values for all observatories are supplied to Committee No. 4. Monthly reports of special events (pulsations, bays, S.S.C., etc.) are supplied to Committee No. 10 for Agincourt, Meanook, and Victoria.

4. Developments in Magnetic Instruments

4.1. Dominion Observatory

A new gyro-stabilized platform for the three-component airborne magnetometer is under construction, making use of the improved gyroscopes now available. A Marconi Doppler Navigator has been incorporated into the instrument to supply more accurate ground-speed and drift information to the navigational computers.

A proton precession magnetometer has been developed which indicates and records the field intensity directly in gammas or tenths of gammas (Serson, 1961, 1962b). An experimental three-component proton precession magnetometer, which records a complete set of readings every minute on punched tape, has been successfully operated for periods up to 20 days. Digital computer programs for reduction of the data, rejection of erroneous readings and calculation of hourly means have been developed (Serson, 1962a). Improved circuits have been developed for transistorized portable fluxgate magnetometers, and progress has been made in the development of portable transistorized proton magnetometers.

A semi-automatic magnetogram reader has been designed and built and is now in use at Victoria Observatory (Caner and Whitham, 1962). With this system the operator tracks the magnetogram manually, while the machine computes hourly means, multiplies by the appropriate scale factor, adds baseline values, and types out the result in tabular form.

4.2. Geological Survey of Canada

A spinner-type magnetometer incorporating an air-driven turbine has been built. An astatic magnetometer has been completed for use in a regular laboratory building. The design includes special features to overcome the effects of large magnetic gradients and vibrations, and to reduce the time required for measurement.

A new proton magnetometer system for low-level aeromagnetic surveys has been developed. The signal from a proton magnetometer carried by a light aircraft or helicopter is telemetered by frequency-modulated radio, through an airborne repeater station to a ground station. Signals from a fixed proton magnetometer at the ground station are compared with the airborne signals, and the difference in magnetic fields is recorded. The system presents a great advantage in mountainous country, because complicated flight patterns can be flown according to the terrain without the necessity of control lines and datum adjustment. A survey of over 5,000 line miles was flown over Vancouver Island in 1962 using this system.

4.3. Other Developments

At the Pacific Naval Laboratory the development of low-noise, low-impedance micropulsation receivers has continued. Three-component systems for measurement of geomagnetic background between 0.01 and 30 cps (English *et al.*, 1961) are now in general use.

At the University of Alberta considerable effort has also gone into the design and construction of optimum coils and photo-cell amplifers for detecting pulsations. Signals are recorded on seven-channel magnetic tape recorders in the field. A high-speed multi-channel analog-digital conversion system has been built to prepare records for computer analysis.

Barringer Research Limited of Toronto has developed and made commercially available a portable transistorized proton precession magnetometer which reads total intensity directly in tens of gammas. The instrument is battery operated and features very low power-consumption (Barringer and Kagan, 1961).

5. Interpretation of Aeromagnetic and Ship Magnetometer Surveys

5.1. Geological Survey of Canada

Geologic-aeromagnetic correlation studies have been completed and published for several map-areas in the Northwest Territories (MacLaren, 1961, 1962a, 1962b).

A preliminary report (MacLaren) has been completed for the interpretation of the "Roads to Resources" area in northwestern Ontario, surveyed in the federal-provincial program. Magnetic-susceptibility and specific-gravity data from 7,500 rock samples from this area, as well as other petrographic and geochemical data are being used in further correlation studies.

Interpretation of an aerial magnetic and radiometric survey in the Arctic Archipelago has been completed and published (Gregory, Bower and Morley, 1960). An interpretation of the reconnaissance ship magnetometer data taken in Hudson Bay in 1961 indicates the existence of a sedimentary trough in the central part of the bay extending to a maximum depth of about 10,000 feet.

5.2. Institute of Oceanograhy, Dalhousie University

High-level aeromagnetic data from Dominion Observatory surveys and U.S. Project Magnet have been used in the investigation of the continental shelf and slope off the Canadian eastern seaboard and the region of the Mid-Atlantic Ridge. Large anomalies have been found on the continental shelf and slope north of Newfoundland and northeast of Newfoundland and Labrador. A large anomaly also appears over the Ridge in most of the flights. More detailed work at sea is being planned on the basis of these results.

5.3. Dominion Observatory

A quantitative evaluation and comparison of the techniques of base-looping and ground-monitoring for eliminating geomagnetic time variations from total-intensity flight records has been made (Whitham and Niblett, 1961).

A study has been done of the accuracy of three-component airborne magnetic measurements in relation to the problems of representing the geomagnetic field by world charts (Serson 1960). It is shown that airborne surveys can increase the accuracy of magnetic charts even in regions with a reasonable distribution of accurate observations on the ground.

6. Paleomagnetism and Rock Magnetism

6.1. Geological Survey of Canada and Dominion Observatory

A paleomagnetic study of Palaeozoic rocks from Prince Edward Island has been completed at the Geological Survey. Projects to study the structural history of the Sudbury Basin area (Hood, 1961) and the Lewis Thrust Plate of the Canadian Cordillera (Norris and Black, 1962a, 1962b) from paleomagnetic directions have also been completed. A paleomagnetic study of Proterozoic rocks from the Purcell system in southwestern Alberta, Saskatchewan, and British Columbia has been published (Black, 1962), as has a study of rocks from the Monteregian Hills in the Eastern Townships (Larochelle, 1962). Rocks from eleven geological units ranging from the Proterozoic to the Devonian in eastern and central Newfoundland have been measured for magnetization directions. Further specimens have been collected in Newfoundland and on the south coast of

Labrador. Oriented samples have also been collected in northern Yukon for an attempt to apply paleomagnetic data to the solution of structural geology problems.

At the Dominion Observatory, studies have been completed on the response of an astatic magnetometer to cylindrically-shaped rock specimens (Roy, 1963a) and on general design considerations in the construction of a sensitive astatic system (Roy, 1963b).

6.2. Canadian Universities

At the University of Western Ontario the magnetic properties of solid solutions of ilmenite and hematite have been investigated using natural and heat-treated crystals from the Allard Lake region in Quebec (Carmichael, 1961, 1962). A new range of composition in the solid solution series has been found to reverse its magnetic polarity with change in temperature.

The magnetization of a pyroxenite from Wilberforce, Ontario, has been found to be due to very fine needles of magnetite that have exsolved out of the pyroxene (Irwin, 1963). They have a high coercive force of 600 to 1,000 oersteds. Magnetic minerals responsible for the magnetization of some plateau basalts from India are being studied.

Precambrian and early Canadian basic intrusives in Ontario are being studied for determination of ancient pole positions for rocks that can be dated by radiogenic means. This work is part of the Canadian contribution to the Upper Mantle Project.

At the University of Toronto a study of magnetic properties of Precambrian diabase dykes was completed (Strangway, 1961). The direction of stable remanent magnetization was found to be close to the strike of the dyke, and an explanation of this was based on the demagnetizing effect of the shape of the dyke and the presence of magnetic minerals with different Curie temperatures. An investigation of the effect of temperature on remanent magnetization has been made (Krause, 1960).

Work has begun at the University of Manitoba on regional magnetic anomalies, and on the distribution of magnetic properties in the rocks of various tectonic regions. The areas under study are the boundary between the Superior and Churchill geologic provinces, and the Keewatin lava belts in eastern Manitoba and adjacent parts of Ontario. Aeromagnetic maps of these localities are being used for analysis as well as the measured magnetic properties of oriented rock specimens collected at regular intervals, and vertical-force magnetic-field measurements made at the collection sites. One of the objectives is to see if major structures at depth in the Canadian Shield are reflected in the magnetic anomalies.

At the Saskatchewan Research Council and the University of Saskatchewan, theoretical work has been completed on the interpretation of magnetic anomalies over sheet-like bodies with arbitrary direction of polarization and unknown base level (Hall and Vawter, 1961; Mader, 1962).

At the University of Saskatchewan, oriented rock specimens from the orebody at Coronation Mine and nearby are being used to study the influence of geological and geochemical conditions on magnetic properties of rocks.

7. The Main Geomagnetic Field and Secular Variation

At the Universities of Toronto and Waterloo, theoretical studies have been made of the effects of changes of the magnetic field at the core-mantle boundary on the earth's rate of rotation, due to electromagnetic coupling of the mantle to the core (Rochester, 1960, 1962). Changes in the length of day at a rate of a fraction of a millisecond per decade can be accounted for by the observed rate of secular variation. A study of the effect of the conductivity distribution in the mantle on the tightness of the core-mantle coupling has shown that a time constant as low as 10 years is consistent with the conductivity profile as presently estimated (Roden, 1961). The possibility of exciting the free nutation (Chandler Wobble) of the earth's axis of rotation via electromagnetic coupling has been investigated. The maximum torque available was found to be much too weak to provide the observed motion of the pole of rotation.

8. Geomagnetic Disturbance, Pulsations, and Aurora

8.1. Conjugate Point Experiments

During January 1961 the Pacific Naval Laboratory of the Defence Research Board and Stanford University carried out a cooperative experiment to measure electromagnetic background noise from 0.003 cps to 15 kc at Byrd Station, Antarctica, at its near conjugate, Great Whale River on the eastern shore of Hudson Bay, and at Churchill, Manitoba (Lokken *et al.*, 1961). The three stations are in the auroral zones. PNL equipment measured three components of micropulsations in the frequency band from .003 cps to 3 cps, and the vertical component in the ELF band between 2 and 30 cps (Lokken *et al.*, 1962a). Single components of micropulsations were also recorded at the mid-latitude stations, Ottawa and Albert Head (near Victoria). The Stanford equipment covered the VLF band from 15 cps to 15 kc.

Between 0.003 and 3 cps, two classes of micropulsations (impulsive bursts and regular signals) have been recognized. The distribution of these with latitude, their association with visible aurora, and their degree of similarity at conjugate stations, have been reported (Lokken, Shand and Wright, 1962a, 1962b).

Between 2 and 30 cps, the first three modes (8, 14, and 20 cps) of earth-ionosphere cavity resonance were conspicuous on the records from Byrd and Great Whale (Lokken *et al.*, 1961; Lokken, Shand and Wright, 1962a, 1962b). A notable feature of these records was the occurrence of large-amplitude bursts of one or two seconds duration which appear to show remarkably high coincidence between conjugate points.

8.2. Power Spectra, Coherence, and Statistical Studies at the Pacific Naval Laboratory

Measurements were made to study the coherence of micropulsations over a 46-km path near Ralston, Alberta, in 1960. Phase difference in horizontal components with periods of about 30 seconds suggests the presence of a conductivity anomaly. A further analysis of power spectra, coherence, and phase relationship has been done for daytime micropulsation activity at Albert Head and Borrego Springs, California, using simultaneous data (Lokken, 1961). Spatial variations in geomagnetic micropulsations have also been studied between Albert Head, Bear Creek on Vancouver Island, Borrego Springs, Summerland in interior British Columbia, and Ralston in Alberta (Duffus *et al.*, 1962).

Investigations of relative magnitudes of vertical and horizontal components of micropulsations indicate that low values of Z/H are associated with regions of uniform conductivity and permeability, while high values are associated with gradients and discontinuities (Duffus *et al.*, 1962). However, for measurements made in the valley and delta of the Fraser River (Christoffel *et al.*, 1961) the expected decrease of Z/H on the land side of a land-sea interface was not obtained. A theoretical investigation has been made of the variation of Z/H in a model earth, consisting of a flat semi-infinite conductor divided into two regions of different conductivity by a vertical plane normal to its surface (Weaver, 1963). Simultaneous measurements on the east coast near Halifax, and on Sable Island, were made in 1962; and in this case the observations were consistent with theoretical predictions. Near the auroral zone, high values of Z/H can be attributed to the distribution of current sources in the ionosphere as well as to geological features (Dosso and Lokken, 1961; Lokken, Shand and Wright, 1962a; Weaver, 1961).

8.3 Studies at the University of British Columbia

In cooperation with PNL, a permanent observing station has been established at Westham Island, 25 miles south of Vancouver, where rapid changes in the magnetic field—with periods from about 0.3 to 100 seconds—are recorded on chart paper and magnetic tape. Equipment has also been installed to extend the frequency range to 40 cps when required.

Diurnal and world-wide characteristics of geomagnetic micropulsations recorded during the IGY have been derived (Jacobs and Sinno, 1960a, b), and the equivalent overhead current systems which may give rise to the micropulsations have been constructed.

Conspicuous micropulsations in the auroral zones with periods from 0.03 to 10 seconds have been

studied and grouped into four classes. Possible physical mechanisms have been suggested for the generation of each class.

Further investigations on the L.M.T. or U.T. dependence of magnetic pearl-type oscillations have been made (Jacobs and Jolley, 1962). In many cases the onset of pearls appeared to be entirely dependent on L.M.T. No relationship was found between their occurrence and other upper-atmosphere phenomena.

A detailed study of world-wide changes in the geomagnetic field has been carried out (Nishida and Jacobs, 1962a, b, c). Particular attention has been given to their equatorial enhancement, and theories of their origin have been considered.

The equations of small hydromagnetic oscillations in cylindrical coordinates with the main magnetic field lying in the plane perpendicular to the axis of the cylinder have been derived (Westphal and Jacobs, 1962), and the eigenperiods of toroidal oscillations as a function of latitude were obtained without making any approximations. Using an electronic computer the calculations have been extended to the case of a non-uniform plasma density distribution and to the case of a dipole field deformed by the solar wind to lie within the magnetosphere.

A number of theoretical investigations on hydromagnetic wave propagation in the lower exosphere have been made (Jacobs and Watanabe, 1962). It has been shown that hydromagnetic waves with certain special frequencies incident in the polar regions may be selectively amplified in the upper atmosphere. Pearl-type magnetic pulsations may arise from the finite bard width of the characteristic frequency. The law of electric conduction for transverse waves propagated along a strong external magnetic field in a slightly ionized gas has also been investigated (Watanabe, 1961a, b). These results are applicable to the ionosphere which is slightly ionized and permeated by the terrestrial magnetic field.

8.4 Studies at the University of Alberta

At the University of Alberta, analyses of micropulsation pearls has shown that they can sometimes be highly stable oscillations containing at least two distinct time-independent spectral bands, each with a Q of 20 or more (Vozoff, Ellis, and Garland, 1962). Their polarization indicates that they are waves that have travelled through refractors slowly varying in time. The amplitude envelope does not appear to be due to the addition (beating) of two such distinct bands.

A set of cooperative experiments by the University of Alberta, the University of British Columbia, the University of Texas and PNL was made in 1960 to study areal coherence of magnetic pulsations (Smith, 1962). Although the interval turned out to be too quiet magnetically, it was found that there was sometimes a very strong resemblance, and high spectral coherency between fields in Texas, Arizona, and southern Alberta.

8.5 Geomagnetic Disturbances and Aurora

In a study of IGY auroral and geomagnetic data at the University of Toronto, a close correlation was established in space between individual auroral displays and the ionospheric current paths associated with simultaneously occurring geomagnetic storms (Sobouti, 1961).

This work is being extended at the Dominion Observatory where a study of the position and intensity of the auroral electrojet is in progress, using data from North American and polar-cap magnetic observatories operated during the IGY.

8.6 Other Studies of Magnetic Time Variations

A unifying theory of high-latitude geophysical phenomena, including geomagnetic agitation and bay disturbances, aurorae, and various irregular distributions of ionospheric electrons, has been developed by Defence Research Board scientists (Axford and Hines, 1961).

A study of the complicated surface distribution of irregular geomagnetic disturbance (agitation) and of sudden commencement impulses has also been made at DRB (Hope, 1961).

At PNL a comparison between geomagnetic fluctuations and records of ionospheric soundings at Victoria has been published (Shand, 1962).

At the Dominion Observatory a study of hourly range data in three components for the year 1960 has been completed for the Canadian magnetic observatories at Victoria, Meanook, Churchill, Baker

Lake and Resolute Bay (Loomer and Whitham, 1962). An account of the large geomagnetic disturbances at Canadian observatories in November 1960 was published (Niblett, 1961).

9. Magnetic and Electric Field Variations and Upper Mantle Conductivity

At the University of Alberta, vertical electric field variations have been monitored by placing electrodes in a bore-hole, and significant signals which correlate with magnetic activity have been recorded (Garland and Webster, 1960; Garland, 1962). Magneto-telluric measurements have been used with considerable success to estimate the depth to basement and to major conductivity variations within the sediments of the Alberta basin. The effects of complex or non-uniform fields on conductivity interpretations of the Cagniard type are under investigation.

A combined field operation was carried out in 1961 by the Universities of British Columbia, Alberta, and California (Berkeley) and PNL to measure simultaneous magnetic and electric variations at six field stations in the plains of Alberta. The stations were about 100 km apart and in an approximately north-south line. Apparent-resistivity analyses made at two of the stations indicated a three-layer earth model, the bottom layer being of reduced resistivity at a depth of 60-70 km.

Studies of the vertical boundary problem in magneto-telluric theory have been made at the University of Alberta (Rankin, 1962) and PNL (Weaver, 1962). The theory of electromagnetic induction in a conducting cylinder located in the near field of an alternating line current has been developed (Weaver, 1961).

For the Upper Mantle Project, magneto-telluric investigations are being continued in western Canada by the University of Alberta and the Dominion Observatory. Also planned is a joint program among Canadian universities to detect and investigate anomalous mantle conductivity by using closely spaced networks of magnetic (three-component) variation stations.

At Alert on Ellesmere Island the anomaly in the level of irregular magnetic activity first noted during the IGY, has been investigated further by the Dominion Observatory (Whitham and Andersen, 1962). Analysis of additional three-component observations in the vicinity of Alert indicates that the effect is of internal origin and is caused by a large body of anomalous conductivity striking parallel to the channel separating northern Ellesmere Island from Greenland. Another conductivity anomaly appears to exist near Mould Bay on Prince Patrick Island, and this is being investigated by the techniques of spectral analysis. Further field work in the area is planned.

10. Electromagnetic and Electrical Prospecting Methods

10.1 Geological Survey of Canada

Field equipment for groundwater prospecting is being developed. One system is designed to measure the polarizability of earth materials, in particular the membrane polarization of clays. Another electromagnetic system will measure variations in radiation resistance of a loop as it is passed over the ground. These variations depend to a large extent on changes in the permittivity of the ground.

A laboratory program to study the membrane polarization mechanism of clays and rocks has been started. Scale-model studies in both continuous wave and pulse methods are in progress.

On the theoretical side, studies of the electromagnetic fields of a magnetic dipole over both a homogeneous and layered earth are in progress. Investigations on the radiation resistances of vertical magnetic and horizontal electric dipoles placed over a homogeneous earth have been completed. Analysis of some theoretical aspects of electrode polarization in rocks has also been made.

10.2. University of Alberta

Numerical methods of directly interpreting conventional resistivity surveys were extended to the use of linear programming techniques (Vozoff, 1960). These are currently being applied to groundwater problems at the Alberta Research Council.

10.3. Dominion Observatory

Conventional resistivity measurements were made across the crater formation at Holleford, near Kingston, Ontario, during 1961 and 1962. The results suggest a meteoric rather than a volcanic origin for the formation.

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Part II. Aeronomy

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1. Spectrographic and Photometric Studies

The principal centres for spectroscopic studies of the emissions from the upper atmosphere are at the University of Saskatchewan in Saskatoon and at the Defence Research Northern Laboratory at Fort Churchill. Much of the airborne work (using aircraft and balloons) is done at the Canadian Armament Research and Development Establishment at Valcartier, Quebec, and much of the laboratory work is done at the University of Western Ontario.

1.1 Twilight Emissions

Very faint natural lithium emission has been observed, along with some evidences for increases in November and January. In addition, a large increase was observed in November 1961, probably caused by a large thermonuclear explosion; and a very large increase in November 1962, almost certainly caused by an explosion at about 50 km. During this large increase the fine structure of the Li line was observed with a photoelectric interferometer, providing a positive identification of it. Li^6 only was detected; the abundance of Li^6 must be less than or equal its natural value of 7.5%. Potassium was also found for the first time; comparison of the abundances of Na, K, and Li favors a marine origin for the first two, and a meteoritic origin for Li. The seasonal variation of sodium abundance at 44° S. was found to be six months out of phase with the variation at 52° N.

The O–O band of the infrared atmospheric system of O_2 was observed from an aircraft at 13 km, both in the daytime and in twilight.

Simultaneous observations of ratio and brightness of the sodium D lines were made with a photoelectric interferometer. The results agree well with the theoretical predictions based on the assumption that the daytime abundance of Na is the same as during twilight.

1.2 Infrared Studies

Infrared spectra have been obtained in the 1.5 μ region with spectral slit widths of 25 Å. Temperatures for OH bands in this region were determined. The seasonal variation of the 1.58 μ O_2 atmospheric band was observed to have a strong mid-winter maximum.

As part of a program of airborne infrared solar spectroscopy, studies are being made of water-vapour absorption in the vicinity of the tropopause.

A series of observations have been made on high-altitude infrared airglow from a balloon platform at 100,000 feet. Seven balloon flights have yielded spectral data; three measurements covering the 4–8 micron range and four the 2–4 micron interval. The $\Delta V = 1$ sequence of OH has been seen both night and day and a series of other features at longer wavelengths have been observed which appear to be partly thermal and partly photochemical in origin. Features observed include emission bands at 3.25, 4.4, 4.8, 5.35, 5.45, 5.6, 5.9, 6.2, 6.5, and 7.7 microns. Most of the features are thermal radiation from atmospheric gases: CO_2 at 4.4 μ, O_3 at 4.8 μ, CH_4 and N_2O at 7.7 μ and water vapour from 6 to 6.5 μ. The 6.2 μ peak vanished after sunrise. Intermittently, signals have been observed near 5.3 microns. The 5.9 μ emission does not appear to be entirely due to water vapour whereas the 6.5 μ peak can be identified as water vapour.

Equipment has been constructed for high-altitude solar spectroscopy, for solar scattering measurements in the infrared, and for interferometric studies of airglow from 100,000 feet.

1.3 Studies of the N_2^+ Bands, and Temperature Measurements

The fluorescence of these bands in sunlit aurora and in undisturbed twilight was observed photoelectrically. Some auroral displays show no detectable effect; others do give a small effect, and it appears that these always lie above 130 km. Apparently N_2^+ ions are very rapidly removed below this height. Some evidence was found for twilight emission in 1958, but it has since disappeared. This phenomenon may occur in the F region, with the ionization produced by solar extreme ultraviolet.

N_2^+ rotational temperatures were measured photographically with short exposures, and photoelectrically with a direct-reading device which gives an indication in 1 second. A temperature profile for the atmosphere was constructed from 90 to 170 km.

Temperatures were also found from Doppler line widths of the forbidden oxygen lines. Values as high as 2000° K were found, and temperature gradients were observed in the vertical dimension of auroral forms.

A Fabry-Perot interferometer has been constructed by the National Research Council, Ottawa, in which fringes produced by the auroral green line (OI λ5577) are scanned by thermal expansion of the etalon. Kinetic temperatures of the OI atoms will be calculated from the observed widths of the fringes. This program will continue over the next sunspot cycle.

1.4 Studies of Hydrogen Emissions

High-speed patrol spectrograph observations have shown the existence of a systematic tendency for a zone of hydrogen emission to be located to the south of the brighter auroral forms before midnight. After midnight this zone of hydrogen emission may coincide with or lie to the north of the most southerly bright auroral forms.

1.5 Photometric Studies

Photometric measurements of auroral brightness fluctuations have continued at Saskatoon. Simultaneous recordings made with 4-minute and 1.5-degree fields of view have a high degree of correlation. Power spectrum analysis has shown that periodic fluctuation components with periods ranging from 4 to 15 seconds are common.

At Ottawa two airglow photometers have been designed and constructed by NRC—an "all-sky" photometer using a convex mirror, and a narrow-beam photometer that automatically scans the whole sky. Both use sensitive photomultipliers and narrow-band interference filters to isolate spectral regions of interest. The all-sky instrument gives an index of over-all intensity, while the narrow-beam scanner provides information as to the spatial distribution of airglow luminosity.

1.6 Laboratory Studies

Studies have been made on CO^+, BO, BN, SiN and O_2 band systems. Currently, intensity measurements are being made in the vacuum ultraviolet region on a number of band systems of N_2, N_2^+, CO and CO^+. A number of band systems have also been studied in the near infrared of N_2^+ and NO. Some band systems of CO, CO^+ and N_2 are being studied in the visible. A systematic study has also been made on the factors that influence a degree of dependence of the electronic transition moment upon internuclear separation, and some work has also been done on the placing of relative band strengths of CO^+, N_2 and N_2^+ spectra on an absolute scale by reference to the lifetime measurements.

An atlas of common and important diatomic molecular spectra is being prepared.

A 2-KeV lithium-ion accelerator is being used to study effects of rotational disequilibrium between lithium and nitrogen. A 100-KeV proton accelerator is being used to study the spectroscopy of the beam in a variety of target gases. The very feeble luminescence produced by the X-radiolysis of a variety of atmospheric gases is being studied spectroscopically.

1.7 Theoretical Studies

Franck-Condon factors, r-centroids and other quantities derived from vibrational wavefunctions and related to intensities of molecular spectra of important diatomic molecules are calculated routinely on electronic computers.

Studies have been made on Klein-Dunham potentials of a wide variety of molecular-energy states, and recently, wavefunctions derived by machine calculations from these molecular potentials have been produced and turned into Franck-Condon factors.

2. Photographic and Visual Studies of Aurora and Noctilucent Clouds

All-sky camera studies are carried out on a continuous basis at Ottawa (National Research Council), Saskatoon (University of Saskatchewan) and Churchill (Defence Research Northern Laboratories).

2.1 All-sky Camera Studies

At Ottawa, auroral occurrence and N-S position are tabulated for every quarter hour (U.T.). A machine has been built which plots on a map the auroral forms as traced out on a projection of the all-sky camera picture. A 16-mm all-sky camera using high-speed colour film has also been operating at the meteor observatory at Springhill, Ontario, since December 1961. As yet insufficient auroral data have been recorded to establish routine methods of reduction.

2.2 Visual Observations

Visual auroral observations were carried out on a routine basis by stations in the Meteorological Service and by volunteer individuals and groups. These observations are plotted on synoptic maps, using two maps per day, and the southern extent of aurora is read from these plots.

2.3 Noctilucent Cloud Observations

Some visual and photographic observations have been made at Saskatoon.

3. Radio Studies of Aurora

Radio and radar studies of aurora are carried out at a number of centres. Radar studies in the UHF band are concentrated mainly at Ottawa (Defence Research Telecommunications Establishment) and at Prince Albert (Prince Albert Radar Laboratory). Radar work in the VHF band has been carried out at Ottawa, Saskatoon, and Churchill by the National Research Council and at Saskatoon by the University of Saskatchewan. A number of bistatic radio studies of aurora have been carried out by the Defence Research Telecommunications Establishment and by the University of Saskatchewan.

3.1 Occurrence and Association with Optical Aurora

The IGY auroral radar network at 48 mc/s operated at four stations: Ottawa, Saskatoon, Baker Lake and Resolute. Since 1960 this program has continued at three stations, Ottawa, Saskatoon and Churchill. Processing these data by machine methods is continuing and this will provide a network study of auroral activity over half a solar sunspot cycle.

Studies have continued of radio aurora at frequencies near 500 and 1,000 mc/s by means of back-scatter or radar techniques, and, at the lower frequency, by means of the effect of auroral ionization on lunar reflected signals.

The bistatic radio systems have provided new information concerning the occurrence and distribution of the ionization responsible for radio reflections. The early results indicate that the "radio-auroral" zone is coincident with that for optical aurora. A significant degree of association was found between the luminosity of optical aurora and the strength of the scattered signal observed on a bistatic radio system.

3.2 Interpretation of Radio Reflections from Aurora

A theoretical study of radio scattering in aurora was carried out, in which both weak scattering and strong scattering were considered. The results of this study were used as the basis for a multi-frequency back-scatter experiment. The observations indicate the occurrence of both weak and strong scattering for radio frequencies between 30 and 100 mc/s.

4. Meteors

During the past three years most of the work in this field has been carried out by the National Research Council.

4.1 Visual and Photographic Studies

A visual team of nine observers has recorded meteors at the meteor observatory at Springhill, Ontario during selected periods of meteor shower activity. During the years 1960, 1961 and 1962, a total of 5,680 meteors were observed at Springhill and records of 22,700 meteors were received from cooperating groups at other places in Canada and

the United States. Meteor spectrophotography was carried out at Springhill in conjunction with the visual program and some twenty different spectrographs were used. Over forty new meteor spectra were added to the world total.

4.2 Radio Studies

A new high-power meteor radar with a peak power from 2–4 megawatts at a frequency of 32 mc/s was put into operation at Springhill, and used in conjunction with the visual and photographic program at the same station. Meteor echo rates recorded with this equipment ranged up to 5,000 per hour, and for the fast showers, over one third of the visual meteors observed had head echoes.

Operation of the low-power IGY meteor radar, peak power 20 kw at 30 mc/s was continued at Springhill on a 24-hour-per-day basis. Over 7 million meteor echoes have now been tabulated on IBM cards and an analysis of five years of records—October 1957 to September 1962—is being prepared. These are being correlated with the visual observations, which have also been machine tabulated.

4.3 Laboratory Studies

At the University of Western Ontario a 4,000- to 5,000-feet-per-second ballistic pellet range is being used to study some aspects of meteor physics in the laboratory. Particular attention is paid to the ablation from solids as they pass through gases and also the spectrum of the very bright flash of light emitted when the pellet is brought to rest on a target.

5. The Ionosphere

The principal centre for ionospheric studies is the Defence Research Telecommunications Establishment in Ottawa. Some studies relating to auroral absorption and radio-star scintillations have been carried out by the University of Saskatchewan, and others relating to the general morphology have been carried out at the National Research Council Laboratories.

5.1 Absorption

A network of riometer stations extending from Resolute Bay to Ottawa has continued in operation, and the data have been used in studies of auroral absorption, polar-cap absorption, and sudden commencement absorption. The polar-cap absorption events have also been studied in the ionosonde recordings, and a theoretical assessment of this type of absorption has been made.

Multiple-frequency measurements of the intense absorption sometimes observed during auroral displays were used to determine the effective heights of the absorbing region, which seemed to vary in a systematic way during each display.

5.2 Ionospheric Sounding

Vertical incidence sounding of the ionosphere has continued at several Canadian stations, and oblique sounding has been carried out on a routine basis on a number of paths in Canada, as well as on a trans-Atlantic path. A top-side sounder was successfully placed in orbit at 1,000 km height and the top-side of the ionosphere is being studied from 0.5 to 12 mc/s in a routine manner. On suitable occasions the records are used with bottom-side soundings to give a complete electron density profile. Data from the vertical incidence sounding and top-side sounding program are being sent to the World Data Centre at Boulder, Colorado.

Studies of oblique sounding and of various scatter modes of propagation are being pursued with an aim to improve communications reliability.

Studies of the D region are being pursued during normal and disturbed conditions by means of the partial-reflection technique, and by monitoring the phase of standard low-frequency transmissions.

5.3 Radio-star Scintillations

An analysis of several years of scintillation data obtained at a station near the auroral zone (Saskatoon) indicated that there was a marked change in the altitude-angle dependence of the scintillations over a period of four years, presumably in response to changing auroral conditions.

Another study of the scintillations observed during aurora indicated that at such times there are strong fluctuations in phase imposed upon the radio waves passing through the auroral ionosphere.

5.4 General Morphology

Statistical work has been carried out by the National Research Council in analyzing standard ionospheric sounding records and correlating these with various phenomena of the atmosphere.

6. Sun-Earth Relations

Studies of the relationship between solar eruptions and such terrestrial disturbances as geomagnetic storms, polar-cap absorption events, and magnetic impulses have continued at the Defence Research Telecommunications Establishment, with particular emphasis being placed on the solar radio noise data. The monitoring of solar noise emissions on a number of frequencies has continued and a phase-sweeping interferometer at 50 mc/s is being used to determine the direction of arrival of the noise emissions.

At the Algonquin Radio Observatory of NRC, the solar spectrum in the frequency range of 20 to 120 mc/s is sampled sequentially 100 times per second and recorded on moving 35-mm film. In order to increase the probability of recording important events with high time resolution the film speed is automatically increased from 2 ft/hr to 16 ft/hr whenever the 2,800 mc/s flux of the NRC solar patrol radiometer rises 5 flux units above the ambient flux level. Polarization of solar radio bursts is observed at 74 mc/s using an equitorially mounted crossed-yagi antenna. By introducing suitable phase delays right and left, circular as well as vertical and horizontal linear components are recorded. The orthogonal components are recorded without phase delays. From these six parameters, the state of polarization of the incident flux is determined by calculation. The film records are read visually and the solar events are classified by type, frequency range, and time of occurrence. Selected events are scanned by a densitometer for detailed study. The relationship between the meter wavelength spectrum and the 2,800 mc/s solar flux is also studied. This program will continue through the next sunspot maximum.

7. Rockets and Satellites

At the Defence Research Telecommunications Establishment, rockets have been instrumented to measure radio absorption during ionospheric disturbances and at Churchill several have already been fired. A satellite experiment measured the intensity of cosmic radio noise at 3.8 mc/s. On September 29, 1962, a top-side sounding satellite, "Alouette" or 1962 Beta Alpha One, was successfully launched. This satellite also has a VLF receiver for the measurement of whistlers and ionospheric noise, a number of particle counters for an NRC experiment, and can measure cosmic and solar noise in the frequency range 0.5 to 12 mc/s.

Several other rocket experiments have been prepared or will soon be prepared by the laboratories of the National Research Council and the Universities of Toronto, Western Ontario, Saskatchewan and Alberta. These experiments include several different types of electron density measurement, energetic particle counting, magnetic field measurements, photometric and spectrographic observations, and micro-meteorite counting.

8. Cosmic Rays

Cosmic-ray measurements during the past three years include measurements on the ground near sea-level, on one mountain station, in rockets and in the Alouette satellite. Five ground stations have been in continuous operation since the beginning of the IGY. These are on Sulphur Mountain, near Banff, Alberta (operated by the University of Alberta, Calgary); at Churchill, Manitoba (operated by the National Research Council with the assistance of the Defence Research Northern Laboratory); at Resolute, in the Arctic Islands (operated by the National Research Council); at Ottawa (operated by the National Research Council); and at Deep River, Ontario (operated by Atomic Energy of Canada, Limited).

Each of these stations has a neutron monitor and a large cubical counter or scintillation telescope. The results from these are forwarded to the World Data Centre. Plans are in hand to replace the neutron monitors with super-neutron monitors having counting rates of nearly one million counts per hour.

Besides the above, narrow-angle telescopes are operated at Ottawa and underground experiments are carried out in an old mine near Banff. An extensive gamma-ray experiment is being carried out at the University of Manitoba, Winnipeg.

The National Research Council laboratories in Ottawa include a small nuclear emulsion group which has taken part in the International Cooperative Emulsion Flight Collaboration arranged by the University of Chicago.

A series of rocket experiments was carried out in 1958 and 1959 in which the background of cosmic rays was measured outside the earth's atmosphere and the particle content of aurora.

An energetic particle package for particle detection was flown in the satellite Alouette and is producing a great deal of data; at the time of writing very little of these have been published.

9. Theoretical Studies

The Defence Research Board Theoretical Studies Group concerned itself with a number of theoretical studies of hydromagnetic processes in the ionosphere, the magnetosphere and the interplanetary regions. Various aspects of upper atmospheric disturbances were examined and a unifying theory of storm phenomena was advanced. The role of internal gravity waves in upper atmospheric process was studied, as were the incoherent scattering of radio waves from electrons, and mechanisms for driving ionospheric current systems.

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