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CANADIAN NATIONAL REPORT ON GEOMAGNETISM AND AERONOMY

Compiled by
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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: T. R. Hartz) 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 1963. 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, 1963, 1964, 1965, 1966) published by the National Research Council.

Part I. Geomagnetism

Compiled by L. K. Law
Dominion Observatory, Ottawa

1. Geomagnetic Surveys

1.1 Ground Surveys

The Dominion Observatory in its program of charting the secular variations has selected 103 repeat stations, roughly uniformly distributed over Canada, for systematic re-occupation at least once every five years. In addition, auxiliary sites which can be occupied if the original station becomes inaccessible will be tied in with each repeat station. During the field seasons 1963 to 1966, observations were obtained at eighty-seven stations and eight auxiliary stations were established.

As part of a cooperative program with the Geomagnetic Division of the U.S. Coast and Geodetic Survey, in 1965, two stations were occupied in Alaska and a comparison of instruments was made at College Magnetic Observatory.

1.2 Airborne Surveys

The Dominion Observatory's three-component airborne magnetometer survey of November 1963 is shown in Figure 1. Approximately 38,000 line miles were flown over the Canadian Arctic, mostly at an observational altitude of 10,000 feet.

In 1965, the newly rebuilt three-component magnetometer proved very successful during an 84,000-line mile survey of Norway, Sweden, Finland, Denmark, Greenland, the Norwegian Sea, and the Greenland Sea (see Figures 2 and 3). This operation was a joint Canadian-Scandinavian project and included also a survey of Iceland and the mid-Atlantic ridge (Figure 4) which extended south to approximately latitude 61°N, joining the northern limits of a similar survey by U.S. Project Magnet.

The Geological Survey of Canada continued its low-level total-intensity surveys. The areas now surveyed, including the joint Federal-Provincial projects are shown in Figure 5. 501,900 line-miles have been flown on these surveys in 1965 and 1966.

High-sensitivity total-intensity reconnaissance surveys were carried out by a cooperative program between the National Aeronautical Establishment of the National Research Council and the Geological Survey of Canada. In 1964 and 1966 areas of the Labrador Sea, Southern Baffin Bay and Davis Strait were covered by a series of flight lines. A survey of central Hudson Bay was carried out in 1965. The area is bounded by the following co-ordinates 58° 20′N, 89°W; 58° 47′N, 89°W; 58′N, 86°W; and 59° 45′N, 86°W. In 1966 several tracks were flown across the North Atlantic and four lines across the Denmark Strait. Profiles across many of the producing oil fields in Alberta have been obtained.

1.3 Sea Surveys

The Institute of Oceanography of Dalhousie University, in 1963, obtained profiles over the southern edge of the Grand Banks, the Labrador Sea and Nares Strait regions. The Marine Sciences Branch surveyed the Sheet Harbour-Liscomb area and the Tail of the Banks section of the Grand Banks. During the period 1964 to 1966 the Bedford Institute of Oceanography surveyed more than 74,000 nautical miles. The 1964 work consisted of surveys off the coast of Nova Scotia and in Lancaster Sound. The following year, measurements were obtained over Hudson Bay and its approaches, the Atlantic between 44°N and 47°N, and the Labrador Sea, Davis Strait, Baffin Bay regions. In 1966 the three main areas surveyed were the Grand Banks, the Labrador Sea, including a detailed survey of Ungava Bay, and a section of the mid-Atlantic ridge between longitudes 27° 40′W and 27° 20′W and latitudes 48°N and 46′N.

2. Geomagnetic Charts

The Dominion Observatory published magnetic charts of Canada for the elements D, I, H, Z, F and their isopors for epoch 1965 on a scale of 100 miles to the inch. A magnetic chart of the Canadian Arctic showing the mean daily range of magnetic variation and the areal limitations of the magnetic compass was also published.

A preliminary computer listing has been produced of average values for each 5-minute segment of profile from the Scandinavian and North Atlantic three-component aeromagnetic survey. A computer program has been developed for fitting sections of the survey (Iceland, Scandinavia) to the Taylor expansion of the earth's magnetic field and automatically plotting the residuals along the flight lines.

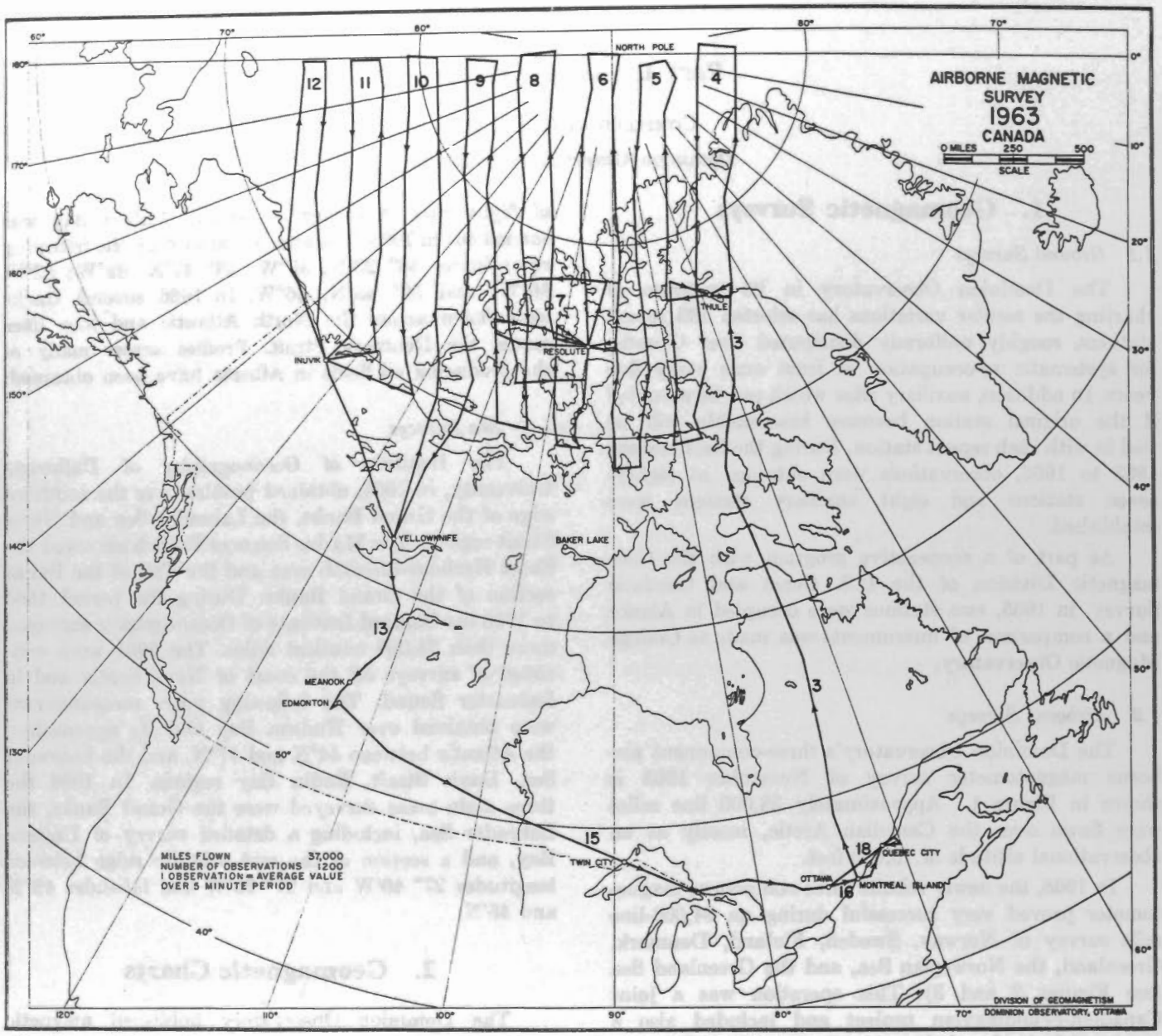

FIGURE 1. Dominion Observatory Arctic survey

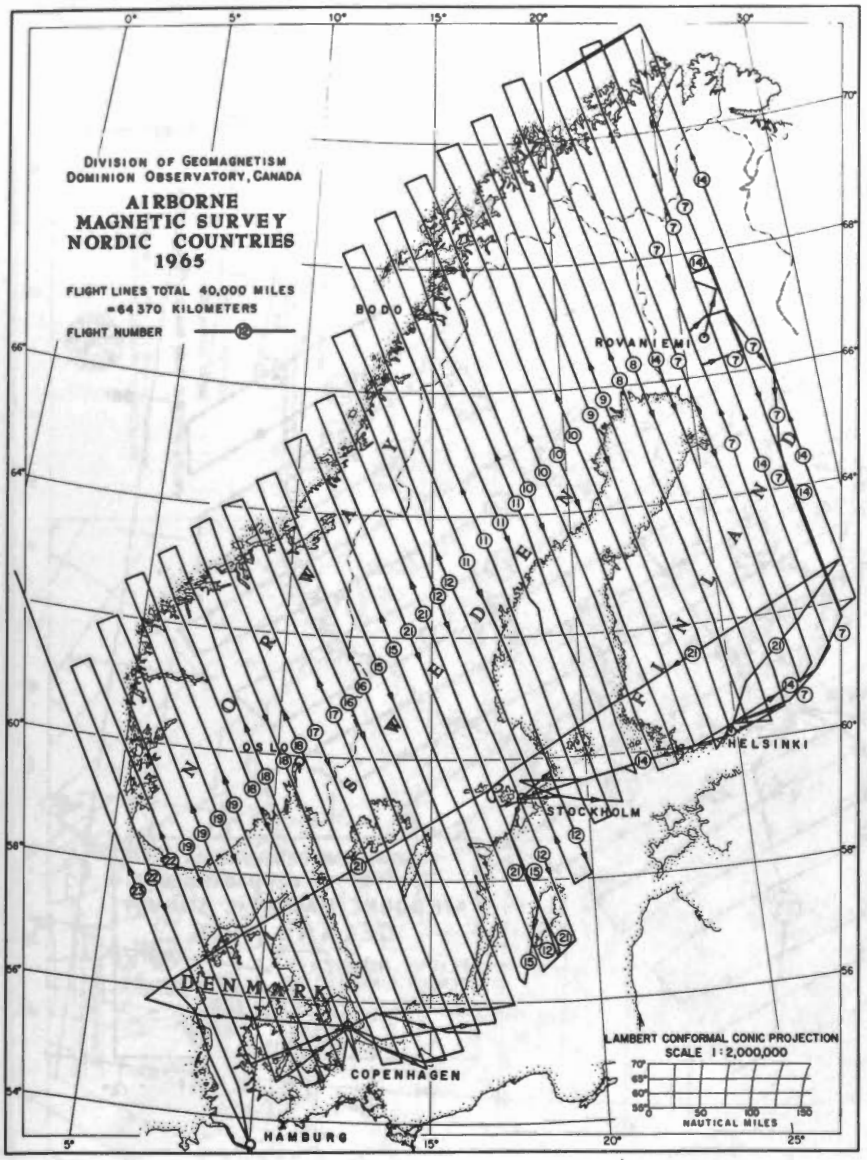

FIGURE 2
Dominion Observatory Scandinavian survey

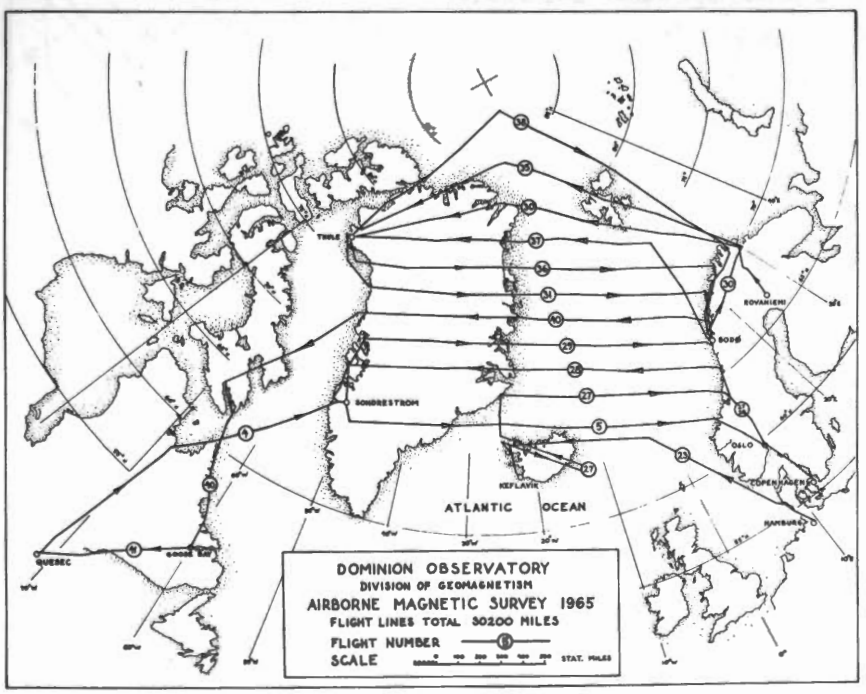

FIGURE 3
Dominion Observatory North Atlantic survey

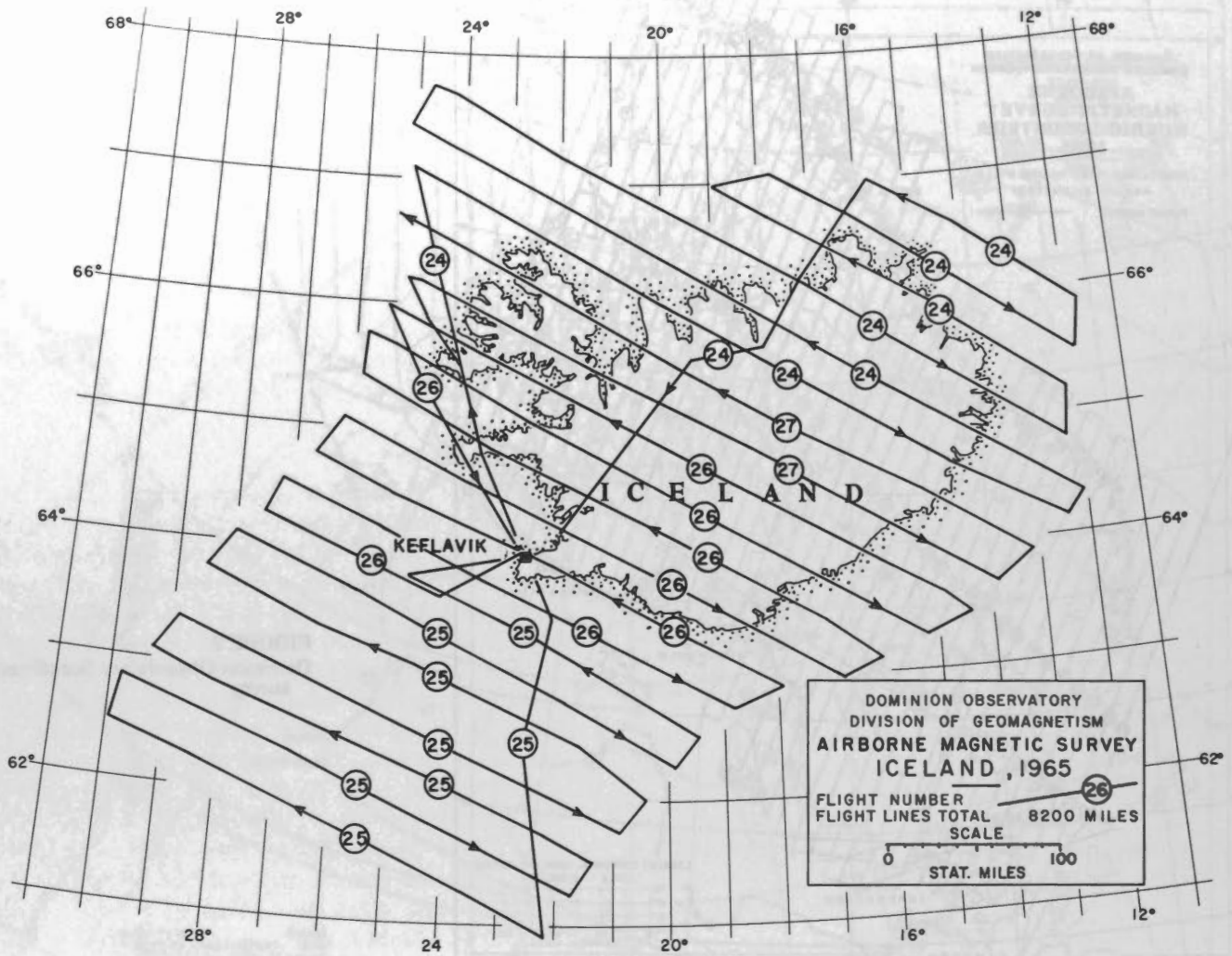

FIGURE 4. Dominion Observatory Iceland survey

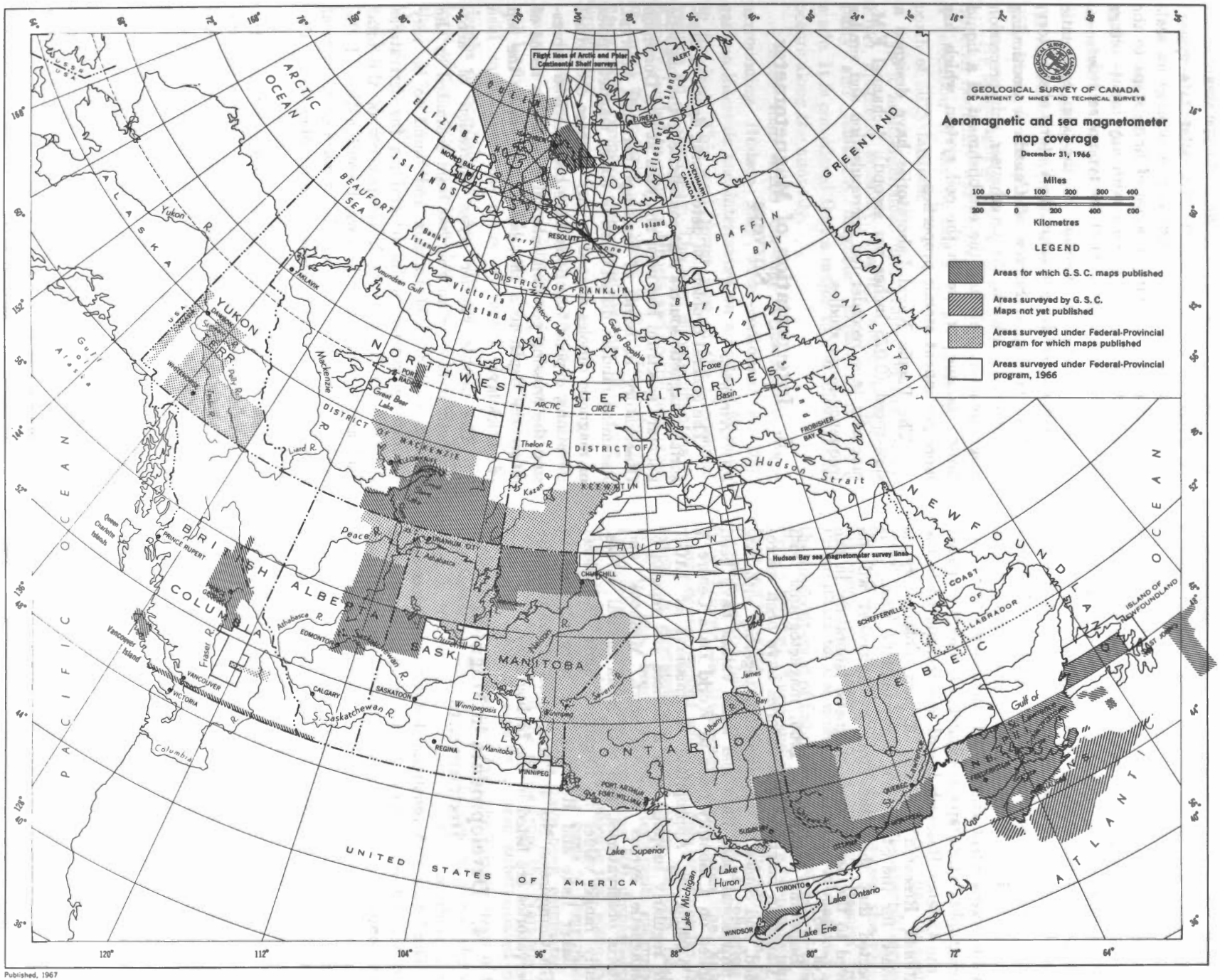

FIGURE 5. Geological Survey of Canada Magnetic coverage

3. Magnetic Observatories

The following seven observatories were operated continuously during the period 1963 to 1966 by the Dominion Observatory; Agincourt, Alert, Baker Lake, Meanook, Mould Bay, Resolute Bay and Victoria. A new observatory at Great Whale River, Que. (55.3°N, 77.8°W) commenced operation in January of 1965. Its location is geomagnetically conjugate to the observatory at Byrd in the Antarctic, operated by the United States and its instrumentation is similar including both standard and rapid-run Ruska photographic variometers. Since 1965 the operation of the photographic variograph at Churchill formerly managed by the Defence Research Board was transferred to the National Research Council. A new observatory is planned for the St. John's, Newfoundland area. It is expected that the observatory at Agincourt will be moved to the new Ottawa magnetic laboratory in the fall of 1967.

Beginning January 1, 1966, magnetograms from all Canadian magnetic observatories have been microfilmed, and copies of the microfilms together with lists of provisional base lines and scale values have been supplied on a monthly basis to World Data Centre A at Washington. Appropriate commissions of IAGA were regularly supplied with K-indices and reports of geomagnetic events for Agincourt, Meanook and Victoria observatories, and with mean annual values. Hourly range values in 10-gamma units (R-indices) for Baker Lake and Resolute Bay were supplied to IAGA Commission No. 4. Publications of the magnetic observatories are listed in the bibliography.

4. Developments in Magnetic Instruments

The National Aeronautical Establishment has outfitted a North Star aircraft with two rubidium-vapour magnetometers, one in a bird towed some 300 feet from the aircraft and the other in a long tail boom. The output from the magnetometers is recorded in both analogue and digital form. The first vertical derivative of the earth's magnetic field is thus measured directly.

The three-component airborne magnetometer of the Dominion Observatory was completely rebuilt. In the new version three-component fluxgates are servo-driven in azimuth to produce D information while H and Z are nulled within a pair of Fanselau coils. The detector-coil assembly is mechanically linked to a new smaller stabilized platform using the improved Honeywell MIG gyros. The data output is recorded on digital magnetic tape.

Portable transistorized three-component magnetometers designed at the Dominion Observatory have been manufactured commercially and are now being used as observatory and field instruments.

A portable, proton precession magnetometer capable of one-gamma accuracy is at the prototype stage.

Also under development is a solid-state system capable of keeping high-sensitivity recordings on scale by sensing and applying a series of finite steps to the trace. This device will operate with any input-voltage function and is independent of the type of recorder.

The commercial version of the semi-automatic magnetogram reader is in use at the Victoria observatory.

The Geological Survey of Canada is continuing development work on the Overhauser spin-precession magnetometer, including the establishment of a liquid proton sample for use in the coil system which has more permanent atomic properties.

The Pacific Naval Laboratories have designed a slow-speed (0.025 inches per second), 4-channel F.M. magnetic tape recorder for micropulsation and similar frequency-range studies.

5. Interpretation of Magnetometer Surveys

5.1. Airborne.

The general problem of determining depth of near-surface magnetic sources that contribute to the magnetic anomaly spectrum has been analyzed at the Dominion Observatory in terms of crossings per unit interval. Assuming random distribution of either magnetic poles or magnetic dipoles aligned in any of three orthogonal directions, explicit functions have been derived expressing the crossing per unit interval directly in terms of either the depth to a thin layer or depth to the top of a thick layer.

The double Fourier series expression of aeromagnetic data over an area has been evaluated by the Geological Survey of Canada and found to be very accurate and convenient for determining the derivatives of the total magnetic field, components of the total field and upward and downward continuation of the field. The method was tested for various theoretical models and individual isolated anomalies have also been studied.

New methods utilizing the characteristics of the independent components of the total field caused by uniformly magnetized rectangular prisms with arbitrary polarization have been developed by the Geological Survey for calculating dimensions, depths to top and bottom and intensity and direction of polarization of the bodies. This method was applied to a large surveyed area in northern Ontario in order to calculate these parameters for deep crustal anomalies. The total field data had first to be stripped of the near-surface, high amplitude components by special filtering techniques. The results were surprisingly consistent, yielding roughly westerly dipping polarization vectors.

The possibility of using power spectral information for determining the dimensions of the bodies causing magnetic anomalies has been studied by the Geological Survey.

Theoretical investigations were carried out on the first vertical derivatives of the magnetic anomalies associated with various theoretical models.

Research is also in progress to develop new methods for calculating amplitude and phase spectrum of two-dimensional aeromagnetic anomalies.

An aeromagnetic-geological study of the Churchill-Superior boundary was carried out. This study suggests a relocation of the boundary to an eastward trend north of 56°N latitude.

In a multi-disciplined field project on the Moose River magnetic anomaly, gravity, magnetic susceptibility and remanent magnetic measurements were made. It is considered that a major zone of dislocations occurs along the anomaly.

More than 1,200 one-mile aeromagnetic maps surrounding Hudson Bay were contoured at 200-gamma intervals and interpreted on a scale of 35 miles to the inch. This work forms part of the Centennial volume on Hudson Bay. The area of interpretation is being extended to eastern Alberta and to the northwest of Great Slave Lake. Its value is in tectonic analysis using both geological and aeromagnetic data over a broad area.

Quantitative interpretation of the available aeromagnetic data over the Canadian Arctic archipelago will be finished by the end of this year. A residual total field map, and two maps continued downward to depths of one-half and one mile respectively from the level of the flight elevation, have been prepared. With the help of these maps it has been possible to calculate the depth to the basement, the Curie-point geotherm and the polarization vectors associated with the causative bodies. These maps have also proved to be very effective in delineating regional and local geological structures.

The cooperative program of the Geological Survey of Canada and the National Aeronautical Establishment of the National Research Council has published interpretations of the surveys carried out over the Labrador Sea, Ungava Bay and Hudson Bay. The advantages of vertical gradient measurements have also been studied and reported. The preliminary interpretation of the recent work over the North Atlantic and Alberta has been completed.

A study of the crustal magnetic anomalies in the western portion of the Superior provinces of the Canadian Shield is being carried out by the University of Manitoba. The magnetic susceptibility and remanence of surface specimens have been measured and various methods of interpretation applied to the aeromagnetic maps.

5.2. Sea Surveys

The Bedford Institute of Oceanography has published the interpretation of the magnetic survey of Lancaster Sound. Interpretations of the magnetics over areas of Hudson Bay, Ungava Bay, Baffin Bay and the Grand Banks were included in more comprehensive oceanographic papers and reports of the Institute. Analysis of the results from the North Atlantic and in particular a section of the mid-Atlantic ridge (see Section 1.3) has been completed.

6. Palaeomagnetism and Rock Magnetism

The Geological Survey of Canada has studied a collection of samples from the Muskox layered intrusion to determine the age relationship between the various intrusions and their cooling history. Results from Precambrian to Mesozoic rocks from Newfoundland and the adjacent coast of Labrador and from New Brunswick, Prince Edward Island and Gaspé have been published. Pole positions for samples of Cretaceous age from Ellef Ringnes Island have been determined. A collection of later Triassic to Quaternary rocks from the Yukon Territory has yielded additional pole positions for that period. A Precambrian group from Victoria Island, N.W.T. has been studied. Remanent magnetism measurements were made on some 500 diabase-dyke-oriented samples and the data indicate that some dyke swarms may be identified on the basis of their palaeomagnetism. Detailed studies have been completed on additional samples of the dykes from the Noranda-Val d'Or and Sudbury regions. A well substantiated pole position has been obtained from the Triassic rocks of the Manicouagan area. Another Triassic pole was derived from a 100-km-long diabase dyke in southern Nova Scotia. Samples of weakly magnetized sedimentary rocks from southern Ontario were measured and so far found inadequate for palaeomagnetic studies. An investigation of the magnetic properties of sulphides is in progress. A study of the magnetization of pot-sherds from southwestern Ontario has shown that the earth's field intensity varied in this area, for the past 5,000 years, approximately the same as in Europe and in Japan. A detailed magnetic and geological survey of the Kapiko iron range was undertaken. Vertical-force magnetic measurements on a close grid and in situ susceptibility results were obtained as well as samples for remanent measurements. The results of these surveys were compared with detailed geological mapping.

Results from upper Palaeozoic red sandstones from Prince Edward Island have been published by the Dominion Observatory. Samples of weakly magnetized Ordovician limestone from southeastern Ontario have been measured. In cooperation with the Lamont

Geological Observatory a study has been made of the palaeomagnetism of Silurian strata in the Appalachians. Rocks from the supposed meteorite crater at Manicouagan have yielded early Mesozoic magnetization directions. A study of the magnetic properties of Carboniferous and Permian rocks from the Maritimes and the Gaspé has been published. Additional work on Carboniferous and Devonian rock from the Maritimes is in progress.

The University of Western Ontario has studied basaltic intrusive formations from the Superior and Grenville provinces of Ontario. Several radiometric dates have been obtained from these units. Oriented samples from the Triassic North Mountain basalt of Nova Scotia give a high-precision palaeomagnetic pole which differs slightly but significantly from other late Triassic poles of North America. This volcanic section is thin and probably represents less time than the period of secular variation. Lava flows and sills of basaltic composition from the Lake Superior region have been studied. All of these units are believed to be in the age range of $1.1 \pm 0.1 \times 10^9$ years. The presence of reversals of magnetic polarity in the sequences of Keweenawan lavas will be an aid in correlating these units from one area to another. A suite of varvites from the Huronian sequence near Iron Bridge, Ontario are being studied to test if Precambrian glaciations were confined to near-polar regions. A collection of Jurassic, Cretaceous and Tertiary rocks were obtained on a research trip to Chile and Peru.

The positive aeromagnetic anomaly associated with the Port Caldwell syenite intrusive at Marathon, Ontario has been studied using remanent magnetic data from oriented samples, vertical and horizontal ground magnetometer traverses, and aeromagnetic data from lines flown at several heights. Computer-calculated anomalies were compared with measured ratios to select a probable source.

A study of the composition of magnetite-ulvospinel exsolved and unexsolved crystals from Indian Basalts has been made using X-ray, Curie temperature and electron probe methods. It has been shown that in exsolved systems the various methods can give discordant results.

A study of the correlation between palaeomagnetic field intervals and rapid changes in the number of biological species has been made.

At the University of Toronto a dual astatic magnetometer system and a non-magnetic press have been built in order to study the effects of stress on rock magnetizations. Provision has been made for the addition of a furnace so that the acquisition of T.R.M. under pressure can also be studied. A careful study of the Néel theory for mono-grains has been completed, with the object of making quantitative comparisons between its predictions and the properties of ultrafine-grained samples. A method of deducing the samples' grain distribution function from experimental data has been devised and applied to the experimental work published by Everitt.

Magnetic susceptibility and remanent magnetization over two areas, Texada Island, B.C. and three townships near Vermilion Bay, Ontario were measured by the research group at the University of Manitoba. Contour maps of the physical properties were prepared and interpreted in relation to the aeromagnetic field and associated petrographic and geochemical studies. A study of the regional distribution of magnetization in the Archaean province of the Canadian Shield from the magnetic properties of the rocks and magnetic anomalies has been completed. The area lies between latitude 48° 45′ and 50° 00′ and longitudes 93° 30′ and 95° 00′. There are three greenstone belts separated by areas of granite and gneiss in the area. Similar work has extended the area to the north and west.

The Memorial University of Newfoundland has studied oriented samples collected from lower Palaeozoic formations on the island of Newfoundland and in southeastern Labrador. Similar samples were obtained on a reconnaissance scale, in Mayo and Donegal counties of Ireland to test the palaeomagnetic correlation, if any, between rock formations in Ireland and Newfoundland. Some rock samples have been obtained from two shoals in the Virgin Rocks area of the Grand Banks 130 miles southeast of St. John's. The rock samples were oriented in situ and recovered by divers carrying underwater breathing apparatus.

7. Magnetic and Electric Field Variations

The Dominion Observatory has published several papers on the magnetic variation anomaly at Alert, N.W.T. These papers describe the results of the field programs, discuss the theoretical limitations, and comment on the geophysical significance of the anomaly. The magnetotelluric results, though confirming the exceptionally high electrical conductivity, conflict in other areas of interpretation. Additional field work to determine the areal extent and tectonic implications of the anomaly is in progress.

The suppression of shorter period magnetic variations at Mould Bay, N.W.T. has been studied both theoretically and by several field programs. The induction of an arbitrary magnetic source over a low-dipping, inclined plane has been examined and applied to the experimental data. Results indicate the presence of a thin (5 to 10 km) highly conductive layer at shallow depths (20-30 km) in the Mould Bay vicinity, whereas at Resolute Bay, 700 km distant, the layer is four or five times as deep. Parkinson induction vectors have

been computed to provide information on the location and nature of the boundaries of the anomaly. Magnetotelluric measurements have been made at Meanook Observatory and at Leduc, Alberta and Penticton, B.C. The method of Price for treating non-uniform inducing fields has been used in the analysis and the theory extended to enable the computation of master curves for any number of horizontal layers.

During the summer of 1964 magnetotelluric experiments were conducted at Oka and Richmond, Que. where fairly large positive gravity anomalies are known to exist. Preliminary examination of the records indicates that no appreciable magnetic variation anomaly exists.

Magnetotelluric measurements have been made on either side of the Gloucester fault (near Ottawa) at a distance of about 8 miles from the feature. At both stations the electric field shows a strong tendency for polarization, while the effect is less marked in the magnetic field. Further field work and analysis are in progress.

Six locations were occupied during the 1966 summer field program in a line from St. John's, Newfoundland to Goose Bay, Labrador. The data are being analysed to see if there is prominent 'ocean effect' associated with the proposed magnetic observatory site at St. John's. The effect of the different crustal structures between the Grenville region and the Recent areas is also being investigated.

Work is continuing on the interpretation of the Victoria short-period anomaly. The effects of coastlines have been ruled out as an explanation for the anomalously high Z fluctuations at very short periods. Parkinson plots are being compared with other geophysical and geological information in order to establish possible correlation in strike direction.

A joint project of the Dominion Observatory and the Department of Geophysics, University of British Columbia is in progress to investigate the correlation of the inland geomagnetic variation anomalies in western North America with seismic low Pn velocities.

Some problems in electromagnetic induction have been investigated theoretically at the Pacific Naval Laboratory in an attempt to determine the effect of geological environment on the micropulsation measurements taken by the P.N.L. group. The effect of coastline was studied, considering the earth as a flat semi-infinite conductor divided into two regions of different conductivities by a plane normal to its surface. The theoretical results agreed well with measurements obtained at Victoria and Dartmouth on the coast, Ralston, Alberta 750 km inland, and Sable Island 170 km out to sea.

The theory of electromagnetic induction in a two-layered earth has been developed for a general inducing field varying periodically in time. Particular attention has been paid to the solutions for the magnetic field components in the top layer, in order to determine the shielding effects of sea-water on external geomagnetic variations.

Five-component magnetotelluric data were recorded by a University of Alberta field party at eight locations, 30 km spacing, along a N-S line crossing the north German conductivity anomaly. Analysis indicated that a considerable portion of the anomaly may be due to a basin of unusually conductive sediments.

Magnetotelluric data have been obtained from ten stations in a traverse about 200 km long in southern Alberta in conjunction with a seismic survey.

Similar data obtained in southern Alberta were analysed and at two stations, Brooks and Beiseker, the data showed a very resistive crust and upper mantle with a decrease in resistivity of about two orders of magnitude near 80 km. At the third station, Vulcan, which is closest to the Rocky Mountains, the decrease in resistivity occurs at a depth of only 35 km.

Recordings have also been obtained at the University's observatory site, about 30 miles south of Edmonton. These were taken simultaneously with the field data, and a comparison of the data from these stations provided information on the extent and morphology of the sources.

Theoretical studies of conductivity analysis are being carried out and specific results on the solution for a continuously variable conductivity distribution have been obtained.

A cooperative program with the Southwest Centre of Advanced Studies, Dallas, Texas is in progress. A three-component portable variometer has been designed and tested along an east-west line across Colorado. A northward continuation of the anomaly discovered by Schmucker in New Mexico has been located near Solida, just west of the Rocky Mountain Front.

At the University of British Columbia a new method has been developed to determine the electrical conductivity of the sub-surface regions of the earth using natural telluric and magnetic disturbances. The method is free of the assumptions in other methods that an inducing field is uniform in space (the magnetotelluric method) or is derivable from a potential function (the magnetic method).

Recordings of the geomagnetic components have been made for several field seasons along two east-west profiles. One profile runs through New Mexico and across the Texas panhandle into Oklahoma, at latitude 35°N. The second profile crosses British Columbia and the Rocky Mountains at latitude 51°N. Both profiles intersect the transition zone between the region of normal amplitude variations in the vertical component and the region of attenuated vertical component variations. Considered in conjunction with earlier

profiles of Schmucker and Hyndman, at latitude 32.5°N and 49.5°N respectively, the project showed that the attenuated vertical component regions are indeed part of a large-scale structure covering western North America.

The University of Toronto extended the line of temporary magnetic variation recording stations into southern Quebec. No anomalous effects were observed in the profile between London, Ont. and Sherbrooke, Que.

During the summer of 1965, the program of magnetic variation measurements in Iceland, started in 1964, was extended. Measurements were made at six stations on a line across the island. These observations together with observatory records for the north Atlantic area, have been digitized and spectral analyses and correlation studies made. There is no reversal of sign of any component across the central rift area and in fact, consistent variation in amplitude must be very small.

In order to facilitate the correction for coastline effect, measurements have been made on a scale model of Iceland, surrounded by a conducting ocean and underlain by a conducting mantle. The variations in each component of the field, for different source configurations and frequencies, have been contoured over the island. It appears from the results that the coastline effect will not seriously disturb the measurements at stations in the interior of Iceland.

At the University of Victoria the effect of geological structure on micropulsations for a plane-wave field was investigated using both mathematical and analog methods. The mathematical model assuming homogeneous conducting layers was extended to describe to a good approximation inhomogeneous layers with the conductivity varying as a function of depth. The results indicated that amplitudes and phases of the varying electromagnetic field components are strongly affected by inhomogeneity of the conducting medium.

A plane-wave analog model for studying the effect various geological structures have on natural electromagnetic variations observed at the surface of the earth, has been constructed. Measurements of both horizontal and vertical field components have been made for sloping model earth-sea boundaries, vertical faults and dykes, sea mounts, cylindrical and ring structures, and sloping and horizontal conducting layers.

McGill University has obtained magnetotelluric measurements in the ultra basic area of Thetford Mines, Que. Natural telluric signals in the range 0.5 to 0.005 sec are being studied, including the vertical component. Man-made micropulsations have been investigated using telluric as well as magnetic data. Signals from electric trains in Montreal were identified as far as fifty miles away. Single-frequency, 8-c/s magnetotelluric measurements are currently being carried out by the Geological Survey of Canada in collaboration with McGill University. These measurements are dedicated to the mapping of near-surface geological features. Preliminary measurements in the Ottawa area and in Bartouille township, Que., have been quite successful.

At the Bedford Institute of Oceanography, impedance relations for non-uniform conductors with plane and spherical boundaries have been derived, and show the similarity between the magnetic potential method and the magnetotelluric method. The impedance relations are presented in such a form that they can be used for any number of different conductivity layers inside the earth. A method of interpretation of magnetotelluric data, when the source field is considered, has been suggested in which the vertical magnetic component is considered as well as the horizontal ones.

An electromagnetic model of the eastern coast of Canada has been built. Magnetotelluric measurements have been made to study the effect of the coast at three locations in eastern Canada in a cooperative program with Cambridge University. Preliminary analysis indicated no marked coastal effect at the three stations, Sable Island, Halifax, N.S., and Fredericton, N.B. In addition to the telluric currents recorded on Sable Island, they were also measured at the ocean bottom about 3,000 feet from the island. The electrodes were placed in a north-south direction about 2,000 feet apart and in water 50 feet deep. The recording was done on the island. Instruments that can be lowered to greater depths to record telluric currents are being designed.

8. Geomagnetic Disturbances, and Pulsations

At the Dominion Observatory an analysis of polar elementary storms observed on the I.G.Y. network of magnetic stations has been completed. Auroral data have been compared with magnetic data and the detailed complex spatial and time correlations studied.

A standard-run three-component Askania variograph was set up and operated near Thetford Mines, Que., for a few days before, during and after, the July 20, 1963 solar eclipse. A comparison of the records from nearby observatories and the station in the path of totality indicated no unusual variations which could be related to the eclipse.

In order to study the extent and nature of long-period conjugacy, five magnetic recording stations were set up along an east-west line centred on Cape Jones, Que. which is conjugate to Byrd in Antarctica.

Preliminary analysis of the records indicated that the spatial extent and the degree of conjugacy as measured by coherency are dependent on frequency

and on the nature of the event. The conjugate coherency at periods of approximately one hour was about the same as the coherency between stations 300 km apart along the east-west line.

The following year (1965) four three-component fluxgate recording magnetometers were operated in the vicinity of Baie St. Paul, Que., which is conjugate to Eights in the Antarctic. The instruments were about 140 km in the geographic north, south, east and west directions from Baie St. Paul and were under the centre of a beam of four 45° riometers at Baie St. Paul. The stations were occupied from June 10th to the middle of October.

Fluxgate magnetometer recordings are being obtained from Frobisher N.W.T. which is near the conjugate of the South Pole station at an L of 14 earth radii. The Frobisher station has been in operation since May, 1965.

Micropulsation measurements obtained by the Pacific Naval Laboratory from Sable Island, 170 km off Nova Scotia, a sand dune overlying some 15,000 feet of sediments, confirmed the prediction that horizontal components there are of the same magnitude as on land areas, but the vertical component is greatly reduced. To obtain data over deep water, including the spatial coherence of the signals, stable buoys with total field magnetometers have been designed and tested. Several stations in the Straits of Georgia and Juan de Fuca, and in the Pacific Ocean off Vancouver Island have been occupied for the purpose of recording micropulsations with a crossed-beam rubidium magnetometer suspended at a depth of 300 feet below the surface from a spar buoy. Vertical accelerometer and compass readings were recorded simultaneously with the magnetometer signals. These experiments led to the observation of magnetic signals generated by long-period ocean swell. Signal periods, corresponding to the swell periods were in the 10-sec to 20-sec range, and fields of more than 1 gamma per metre of swell were measured.

Theoretical studies have been made of some of the problems associated with the ocean buoy experiments. Because the layer of sea-water above the magnetometer provides a screening effect on the micropulsation field, a theory of electromagnetic induction in a two-layered earth has been developed to examine this effect. Detailed numerical calculations have been made for the particular case of induction by a vertical magnetic dipole in the ionosphere. The results have confirmed earlier conclusions based on simpler arguments, namely that the vertical component, although small, is virtually unaffected by the sea-water, whereas the horizontal component is rapidly attenuated to almost zero at the ocean bottom. The magnetic field induced by the motion of ocean waves across the earth's magnetic field has also been calculated. The results have shown that this 'wave noise' may produce an appreciable signal in both submarines and airborne magnetometers. This is because the magnitude of the induced field increases not only with the amplitude of the ocean wave, but also with its period, so that long-period ocean swell of small amplitude may generate greater fields than the shorter period, but larger amplitude wind waves of a rough sea. The results agree well with the measurements obtained from the buoy.

In 1965 a joint experiment was conducted by P. N. L. and the magnetics group of the Flight Research Section of the National Aeronautical Establishment. One of the main objectives was the determination of coherence over distances up to 100 miles between micropulsations recorded simultaneously, on the ground, in the air over deep ocean, and in the sea itself. The operational area was the Bahama Islands, where deep sediments result in a region of few magnetic anomalies, and deep water can be found close to land. The North Star aircraft had two rubidium magnetometers, one in a tail boom and the other in a towed bird. A rubidium magnetometer and component receiver for micro pulsations and ELF were operated as the ground station on the coral beach on Eleuthera Island. Two P. N. L. buoys, each containing a rubidium magnetometer were placed initially in the deep ocean east of Eleuthera Island and later in Exuma Sound, southwest of the island. Some verification of the theoretically determined attenuation of swell noise with depth was also carried out in the open ocean, by using the two buoys simultaneously and varying the depths of the suspended magnetometers.

In 1966 another joint P. N. L.-N. A. E. study was carried out in the Georgia Strait near Comox, B.C. on Texada Island and off the west coast of Vancouver Island, near Tofimo. The results from this field experiment are being compared with those from a laboratory experiment made at the University of Victoria, using a physical analogue of the regions and subjecting it to a horizontal plane-wave of radiation.

A network of micropulsation and Schumann-ELF recording stations was operated by the Pacific Naval Laboratory in cooperation with other agencies in 1964. The location and cooperating agencies are; at Byrd Station (Stanford University) and Eights (Stanford and National Bureau of Standards), Antarctica, at Great Whale River (Stanford and National Research Council), Mont Saint Hilaire (McGill University), Suffield (Stanford and University of British Columbia) and Westham Island (University of British Columbia), in Canada, and at La Spezia, Italy (Saclant ASW Research Centre). The network of stations of direct interest to P. N. L. was reduced in 1960 to the three

stations, Great Whale River, Byrd and Suffield. Continuous recording of the Schumann-ELF range of frequencies higher than about 5 H_z was discontinued at the end of IQSY.

Power-spectrum analysis of the records have revealed that Schumann modes up to the fifth occur prominently, the average power being distributed among them in differing proportions from station to station and day to day. The Z/H ratios are subject to wide variations between stations and at a given station depend strongly on frequency. The Schumann-ELF signals received by the stations in mid-auroral and polar-cap latitude were essentially indistinguishable in amplitude and character and conspicuously independent of most solar, auroral and ionospheric phenomenon.

Two sources of interference with the ELF background were investigated. Man-made electromagnetic noise below 60 H_z is prevalent at most sites located in the vicinity of large power systems. Its most prominent feature is a line near 30 H_z which has been identified with 4-pole induction motors. Seismically induced signals, in amplitude generally below most of the natural background, were observed at two locations on sea ice and also at the Suffield station. The magnitude of motion encountered on sea ice of 2 and 3 metres thickness indicated that such ice can provide an adequately stable platform for the detection of all 3 components of the natural electromagnetic background at micropulsation frequencies and in the Schumann-ELF bands.

A cooperative program with Stanford University to investigate coherency between the conjugate stations of Great Whale River, Que. and Byrd Station, Antarctica was carried out in 1963 and 1964. The joint program also investigated the relationships between auroral hiss, periodic emissions and micropulsation activity. The equipment includes three-component recording of micropulsations (0.003 to 3 H_z) and the Schumann-ELF band (2 to 40 H_z). The National Research Council operates auroral (intensity) equipment and the Dominion Observatory has a regular and rapid-run Ruska variograph as well as a three-component fluxgate magnetometer. Preliminary analysis of the results were carried out at P. N. L. and in 1965 the project was transferred to the University of British Columbia.

A study of the conspicuous micropulsations in the auroral zones with periods from 0.03 to 10 sec has been published by the Institute of Earth Sciences, University of British Columbia. The origin of micropulsations whose periods are the order of fractions of a second to several seconds has also been investigated. A plausible possibility is that they are due to a pocket of hydromagnetic waves which is trapped and guided by a magnetic line of force and is bouncing between two magnetically conjugate points.

The theory that long-period micropulsations of the order of a few minutes are caused by torsional hydromagnetic oscillations of magnetic lines of force in the magnetosphere has been extended to show that such oscillations could give rise to a system of ionospheric currents which are observed as micropulsations on the earth's surface.

The general differential equation which governs the distribution of charged particles trapped in a magnetic bottle with a small normal cross section has been derived. The magnetic field is assumed to vary in time and space. Several applications to Van Allen-trapped radiations have also been discussed.

The possibility that bow waves are generated in the solar wind by the planets has been investigated. Disturbances of the geomagnetic field when the earth crosses the bow wave have been observed and reasonably interpreted by the theory.

A formula has been derived for the propagation velocity from the general dispersion equations of a wave in a partially ionized magneto-active plasma. A chain of five magnetometer stations was set up along a line of approximately 56°N geomagnetic latitude from Victoria, B.C. to Montreal, Que. to study the mode of propagation of activity from a predicted source in the auroral zone to mid-latitude field points. It was found that the attenuation rate of Pi2 type micropulsations, which are closely related to magnetic bays, was a function of their period. This result is in agreement with the suggestion that the mode of propagation may be approximated by a plane-wave travelling through the E region of the ionosphere.

An investigation of ionospheric irregularities and motions associated with geomagnetic micropulsations is being carried out by a Doppler sounding technique with the transmitter in Vancouver and the receiver in Victoria, B.C. The amplitude-time variation of geomagnetic bays has been shown to be not only a function of the build-up and decay of an overhead ionospheric current system but also of the movement of the current system with respect to the field points.

The possibility that hydromagnetic (hm) emissions of frequency around 1 H_z are generated by cyclotron instabilities which take place in the magnetosphere being excited by a stream of charged particles has been studied. It appears that protons with a velocity of the order of 10^8 to 10^9 km/sec are likely to excite the instabilities. For the ion cyclotron mode of hm waves which are relevant to hm emissions, the instabilities are found to be nonconvective and it has been shown how a nonconvective instability in the magnetosphere may give an effect observable on the earth's surface.

The relationship of medium-long period micropulsations, pc3, with VLF emissions in the 1-2 kc frequency band was investigated. The signal strength

of the VLF emissions often changes with a period comparable to that of the pc3 taking place simultaneously. These findings led to the surmise that pc 3's may be due to poloidal-like oscillations in the region below the level of the maximum Alfen velocity. Calculations are completed on the approximate period of poloidal-type oscillations as a function of the size of the magnetosphere which is determined by the speed of the solar wind. The Kp index is a good measure of the solar wind speed. The period-Kp relationship obtained theoretically in this way is in good agreement with observational results.

Several investigations have also been carried out on long-period pc5 micropulsations. It is believed that pc5's are caused by those magnetospheric oscillations which are approximately described as torsional type. Evidence has been produced that such magnetospheric oscillations are caused by Kelvin-Helmholtz-type instabilities taking place at the boundary of the magnetosphere. It has been shown that such an exciting mechanism provides a natural explanation for the diurnal variations of the sense of polarization of pc5's.

The Defence Research Board contract with Sir Charles Wright at the Pacific Naval Laboratory was transferred to the University of British Columbia in 1965. The research which has been carried out jointly with Stanford University has been concerned with the correlation of micropulsations with other ionospheric phenomena measured at the same station and with the correlation of micropulsation activity at the conjugate stations Great Whale River, Que. and Byrd Station in the Antarctic. A detailed analysis of the records from these stations has been completed. A feature of the micropulsation activity is the pronounced difference between day and night records. As both magnetic and micropulsation disturbances are associated with changes in the solar wind, Kp may be regarded as a general measure of disturbance for all frequencies in the latitude range covered by the contributing magnetic observatories. There is a high degree of correlation between the stations of the magnetic and micropulsation field and of micropulsation association with other ionospheric phenomena.

9. The Main Geomagnetic Field Secular Variations

At the Dominion Observatory an analysis of the contribution to secular change of the westward drift of the non-dipole part of the earth's main magnetic field has been completed. The results indicate that, for the earth as a whole, the westward drift can account for most of the secular variation.

A joint investigation was carried out by the universities of Waterloo and Toronto into the possibility of exciting and/or damping the variation in latitude with 14-month period (Chandler Wobble) by electromagnetic torques transferring angular momentum between the core and mantle. It was found that geomagnetic core-mantle coupling fails by a factor up to 10^3 to account for the excitation and by a factor up to 10^5 to account for the damping.

Also at the University of Waterloo work has been done on the general problem of magnetic field diffusion through a spherical shell of variable conductivity and on approximate methods for calculating the time constants for the axial and equatorial components of the electromagnetic core-mantle coupling. An attempt is being made to resolve the controversy over the role of precession on the magnetohydrodynamics of the core.

The feasibility of deducing the distribution of electrical conductivity in the lower mantle directly from the surface observations of the secular variation, without the usual *a priori* assumptions about the form of the distribution on the character of the core field, has been investigated at the University of Western Ontrio and found possible within certain restrictions. Construction of a laboratory model of thermal convection in a fluid under a central force field is in progress. It appears from a study made at the University of Western Ontario that major earthquakes are a possible source of the excitation of the Chandler Wobble. Both experimental and theoretical studies have been conducted on the problem of the attenuation of elastic waves in conducting materials by magnetic field gradients.

Part II. Aeronomy

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1. Spectroscopic and Photometric Studies

Spectroscopic studies of the upper atmosphere are being conducted by the University of Saskatchewan in Saskatoon, in Flin Flon, Manitoba, and at Fort Churchill. The activities of the Defence Research Northern Laboratory at Fort Churchill in this regard ceased with the closing of that establishment in 1965, but some sporadic measurements are being continued there by the National Research Council in support of particular rocket experiments. The National Research Council is also responsible for photometric and photographic observations at Great Whale River, Que. Most of the airborne work (involving aircraft, rockets, and balloons) is carried out by the Canadian Armament Research and Development Establishment at Valcartier, Que., and the universities of Saskatchewan, Toronto, and Calgary. The University of Western Ontario has been active in support laboratory work, some of which is now being continued at York University: the National Research Council has also been active in this capacity.

The Canadian International Year of the Quiet Sun (IQSY) program included patrol spectrographs of the Perkins-Elmer type operating at Saskatoon, Flin Flon, and Churchill, and auroral photometers operating at Baker Lake, Resolute, and Ottawa: the University of Saskatchewan has responsibility for these observations.

1.1 Twilight Emissions

Observations of lithium in the twilight airglow have continued; the principal source, aside from thermonuclear explosions, is deduced to be meteorites. Following a rocket release of lithium the emissions were observed at several locations, leading to results on atmospheric winds and diffusion coefficients. Sodium and potassium abundances have been deduced from twilight emissions and a marine origin for these substances is suggested. Height distributions for these three substances have been determined from the observations.

1.2 Infrared Studies

The $^1\Delta_g - {}^3\Sigma_g$ oxygen bands have been studied in the day, twilight, and night airglow, and seasonal, annual, and evening-morning brightness variations have been observed for which adequate explanations have not yet been found. A four-fold decrease in brightness from 1960 to 1964 has been noted for the 0-1 band (1.58 μ).

Observations of the OH emissions have been made throughout most of a 24-hour period, and the diurnal variations appear to be consistent with a theory of the photochemistry of ozone in a moist atmosphere. Equipment developments have been made, including an all-sky intensity recorder for the 1 to 2 μ wavelength region.

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

Photoelectric observations of these bands have continued, both for twilight conditions and for sunlit aurora: the auroral data have been used to determine rotational temperatures. For the height range 95 to 170 km, a temperature profile during 1964-1965 was found to have a gradient of 4.9 °K per km, which is lower than the gradient obtained in a previous study.

Temperatures have also been determined from Doppler-line widths at 5577 Å in the night glow and the aurora using a wide-angle Michelson interferometer. Doppler measurements at 6300 Å for the day glow, made with a Fabry-Perot etalon, have yielded temperatures in excess of 1200°K.

1.4 Hydrogen Emissions, and Photometric Studies

Hydrogen spectra and their relation to other auroral emissions continue to be studied at several locations. The earlier results on a systematic zone of proton precipitation that appears to move southward before, and northward after, midnight have been substantiated. The pre-midnight proton zone appears to be distinct from the main auroral display, whereas after midnight the two appear to merge.

Photometric studies of the aurora are continuing at Saskatoon, with particular emphasis on rapid brightness fluctuations. Similar measurements are being made at Great Whale River with particular application to conjugate point studies.

1.5 Laboratory and Theoretical Studies

Studies have been made on the N_2^+ first negative system, the second positive system of nitrogen, the Lyman-Birge-Hopfield band system of nitrogen, and the emissions from the system N plus O_2. Some studies of aluminum oxides have been undertaken, and the intensity of the O_2 Herzberg I band system in an oxygen-argon afterglow has been investigated. The excitation of the first negative system of O_2^+ by a proton jet and the rotation energy of N_2^+ bands excited by 3 KeV lithium ions have been studied. The role of metastable oxygen molecules on ozone and airglow was investigated.

A series of identification atlases of common and aeronomically important molecular spectra is under preparation.

Franck-Condon factors and r-centroids are being computed routinely on electronic computers on the basis of the vibrational wavefunctions: in some cases Klein-Dunham potentials have entered into the calculations. In addition, computations have been made of absolute band strengths, and of other spectroscopic parameters.

2. Auroral Studies

2.1 Photographic and Visual Studies of the Aurora

The IQSY program in this field accounted for much of the activity, although there are some continuing studies. All-sky cameras were located at Saskatoon, Flin Flon, Churchill, Baker Lake, Resolute, Meanook, Victoria, and Ottawa. An IQSY visual observational program was also undertaken; this involved the stations of the Canadian Meteorological Service together with various groups of meteor observers, and included noctilucent clouds as well as aurora. The University of Saskatchewan and the National Research Council are the main agencies associated with these observations, and with the continuing work in this field.

At Churchill some auroral height determinations have been made, and other auroral photographic data have been taken in support of particular rocket launches. At Great Whale River studies are underway in cooperation with those at the conjugate station in the Antarctic. Synoptic auroral studies are underway at the University of Saskatchewan and at the National Research Council.

2.2 Radio Studies of the Aurora

Radio and radar studies of the auroral ionization have been conducted at a number of centres. The Defence Research Telecommunications Establishment in Ottawa and its Prince Albert Radar Laboratory have continued earlier work in the U.H.F. band, but most of these activities will terminate with the closing of the latter laboratory this year. The University of Saskatchewan has also been involved in auroral work at ultra-high frequencies. In the main, these U.H.F. studies have been aimed at determining the occurrence pattern and the characteristics of the echoes, and their relationship to the optical auroral phenomenon.

Work in the V.H.F. band has continued under two main groups: the National Research Council, which operated auroral radars at Ottawa, Saskatoon, Churchill, Baker Lake, and Resolute for the IQSY period, and the University of Western Ontario, which has extended its bistatic radio studies and is particularly concerned with the reflection mechanism.

3. Meteors

The main work in this field has been carried out by the National Research Council; some radio studies of meteor trails have been made at the University of Western Ontario.

A study of meteor magnitudes indicated a ratio of 3 in the number of meteors in successive magnitude groups. A survey of meteor spectra was made and a simple system of meteor spectrum classification proposed. A classification has also been made of distinct phenomena in meteor trails.

The Springhill radar meteor patrol has continued, and statistical results on hourly echo rates have been produced. An anomolous increase was noted in the hourly rates of short-duration echoes in mid-1963. Other studies have included the relation between numbers of echoes and their durations, variations in decay rates, and the distribution of ionization along underdense trails.

Instrumentation has been developed to detect micrometeoroids in rockets.

4. The Ionosphere

The principal centre for studies of the ionosphere is the Defence Research Telecommunications Establishment in Ottawa. Some work is being carried on at the universities of Saskatchewan, Western Ontario, British Columbia, and Calgary, at the National Research Council, and at the Dominion Radio Astrophysical Observatory in Penticton. The Department of Transport has responsibility for the standard vertical-incidence ionosonde operations and for the reduction and distribution of the associated data.

4.1 Absorption and Scintillation Studies

Statistical studies have been made of auroral, polar cap, and sudden commencement types of radio-wave absorption using data from a chain of riometer stations extending from Resolute to Ottawa. Absorption studies have also been made with ionosonde f min data. The effects of absorption on HF communication circuits have been considered, and the relationship between

auroral absorption and the influx of energetic electrons into the upper atmosphere has been examined. The feasibility of studying ionospheric absorption on propagation paths involving individual meteor trails was demonstrated. Some relationships between solar flare phenomena and ionospheric absorption were examined, and absorption measurements were made during a total eclipse of the sun.

Scintillation studies at 53 MHz have shown the importance of phase fluctuations, and at 20 MHz it was found that the two magneto-ionic modes can scintillate independently.

4.2 Ionospheric Sounding

Standard, vertical incidence ionosondes have continued to operate at Resolute, Churchill, Winnipeg, Ottawa, and St. John's: the data from these equipments are published for world-wide distribution. At Ottawa, Resolute, and Churchill high-power, fixed-frequency ionosondes (at about 2.5 and 6 MHz) are operating on a non-routine basis for D-region studies. The H.F. oblique circuits from Ottawa to Resolute and from Ottawa to the Hague, Holland, which operated for a number of years, have now been shut down. A number of ground based LF and VLF propagation circuits are being monitored, and the phase and amplitude data are being used for D- and E-region studies.

The two Alouette satellites, with their top-side ionosondes, continue to operate without any serious degradation. The data are being used for a variety of studies of the top-side ionosphere throughout the height range up to 3,000 km, and particularly at high latitudes. Data books are also published and distributed widely, and the ionograms are being deposited in the World Data Centre.

4.3 Satellite VLF Studies

Each of the two Alouette satellites contains a broad-band VLF receiver, and these equipments continue to operate in a satisfactory manner. Proton and helium whistlers have been identified in the recordings; from these data it is possible to determine the ion composition in the vicinity of the satellite. Bands of noise have also been observed consistently; one such has been associated with the lower-hybrid resonance frequency of the local ionosphere. Statistical studies of this particular noise band suggest a dependence on the influx of energetic charged particles.

5. Sun-Earth Relations and Magnetospheric Physics

The National Research Council has continued its 2,800 MHz solar flux measurements at the Algonquin Radio Observatory. In 1964 operations commenced at a second station (Penticton) on a frequency near 2,700 MHz in a joint program with the Dominion Radio Astrophysical Observatory. Information on the total flux and on burst events is being obtained at both sites.

The solar radio spectrum is being sampled in the frequency range 20 to 120 MHz, and polarization measurements are being made on the solar noise at 74 MHz, at the National Research Council. Studies of the solar radio noise in the frequency range 0.5 to 15 MHz are being carried out with the sweep frequency receivers in the Alouette satellites by the Defence Research Telecommunications Establishment. In this same frequency range, bands of noise have been identified which are ionospheric or magnetospheric in origin.

During the IQSY period, an H-alpha solar flare patrol was maintained by the Dominion Observatory in Ottawa. Other studies include flare effects on the upper atmosphere and magnetosphere, various magnetic disturbances and related radio-wave effects, and some eclipse measurements.

6. Magnetospheric Simulation Studies with Laboratory Plasmas

A series of laboratory plasma studies are being carried out at the R.C.A. Victor Company in Montreal in an attempt to simulate various physical conditions in the magnetosphere. These studies include the interaction between the solar wind and the magnetospheric boundary, the variation of the magnetosphere with solar-wind properties, plasma trapping within the magnetosphere and its time history, and the possibility of a lunar magnetosphere. Additional simulation studies have been carried out on space vehicle re-entry and hypersonic flight, satellite sheaths, and radio phenomena associated with the cyclotron frequency.

The University of Toronto Institute of Aerospace Studies is active in a number of laboratory plasma studies which are somewhat more closely related to hypersonic flight.

7. Rocket, Gun, and Satellite Studies

Rocket exploration of the upper atmosphere, using the range at Churchill, is being conducted by a number of Canadian groups; in addition, some experiments have been flown on the American range at Wallops, and on an improvised range at Resolute. The National Research Council is engaged in studies of the ionization using Langmuir probes, and of the energetic electron and proton fluxes that are associated with aurora. Studies of micrometeoroids are also being carried out there. The Defence Research Telecommunications Establishment has been conducting studies on the soft electron ($<$ a few KeV) fluxes, on the electron density distribution in the D and E region, and on some spectral line measurements, all in association with auroral

phenomena: in addition, an experiment is being undertaken to stimulate VLF emissions in the ionosphere. The University of Saskatchewan has been making photometric measurements to obtain luminosity profiles and temperatures on aurora. The University of Calgary is making X-ray and photometric measurements, and the University of Western Ontario is studying ionization inhomogeneities, both of which are in relation to aurora. The Canadian Armament Research and Development Establishment has carried out NO seeding of the upper atmosphere for purposes of determining the height profile of atomic oxygen. The University of Calgary has made some neutron measurements over Resolute.

The Space Research Institute of McGill University has an active development program of gun-launched probes of the upper atmosphere. A series of firings, involving the release of tri-methyl-aluminum, has been carried out for studies of ionospheric winds.

The Canadian satellite, Alouette I, launched in September 1962 continues to function in a satisfactory manner and provides data for about two hours each day. Alouette II was launched in November 1965 and is operating most satisfactorily, giving some six hours of data each day. The Defence Research Telecommunications Establishment has an ionosonde experiment, a cosmic noise experiment, and a VLF experiment in each satellite. The National Research Council has an experiment to measure the flux of energetic particles in several energy ranges in each of these satellites.

A special study on upper atmosphere and space programs in Canada was commissioned by the Science Secretariat and completed early in 1967. All Canadian space and upper atmosphere programs were reviewed and recommendations made for future space activities.

8. Cosmic Rays and Particle Physics

Cosmic ray and energetic particle measurements have continued at ground stations and in rockets and satellites. The National Research Council maintains stations at Ottawa, Resolute, and (jointly with the Southwest Centre for Advanced Studies, Dallas, Texas) at Churchill. Atomic Energy of Canada, Limited, maintains a station at Deep River, Ontario, and, jointly with the National Research Council, is responsible for the stations at Alert and Inuvik in the Arctic Islands and at Goose Bay, Labrador. The Sulphur Mountain Station (near Banff, Alberta) is operated jointly by the University of Calgary and Atomic Energy of Canada, Limited. Each of these stations has a counter or scintillation telescope and a neutron monitor which, with the exception of the Ottawa monitor, is capable of rates of the order of one million counts per hour. At Ottawa the neutron monitor has a counting rate of about 18,000 per hour. Data from these stations are distributed to the World Data Centre on a routine basis.

Additional neutron studies are being carried out with ground monitors at the universities of Manitoba and Victoria.

Studies of the low energy part of the particle spectrum, including the particles trapped in the magnetosphere, are being conducted with rockets and with the Alouette satellite.

9. Theoretical Studies

Most of the theoretical studies that have been undertaken are concerned with phenomena associated with the ionospheric measurements of the Alouette satellite. The various resonances of the ionosphere, particularly the cyclotron resonance and the so-called delayed cyclotron pulse, have been examined, and several aspects of radio-wave propagation and generation have been studied. Tables of the semi-conductor integrals $C_p(x)$ have been prepared for use with the generalized Appleton-Hartree magneto-ionic formulas.

A comprehensive summary of the physics of the earth's upper atmosphere has been published as a text book.

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