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GEOMAGNETISM

BY

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INTRODUCTION

This report has been prepared on behalf of the sub-committee on Geomagnetism and Aeronomy (Chairmen: R. G. Madill—Geomagnetism; P. A. Forsyth—Aeronomy) of the Associate Committee on Geodesy and Geophysics of the National Research Council of Canada. It has been compiled from material submitted by university departments and government institutions undertaking geomagnetic studies in Canada. Information on the extensive ground and airborne exploratory activities of commercial companies is not available to the compiler, and this account is limited to activities primarily of a non-commercial nature. Annual reports on geomagnetism and aeronomy have appeared in the Canadian Geophysical Bulletin (Garland, 1957, 1958, 1959) published by the National Research Council.

The considerable expansion in geophysical activity in the Canadian Department of Mines and Technical Surveys and in Canadian universities during the period under review has resulted in a large increase in geomagnetic activity in Canada since the last national report (Madill and Forsyth, 1957). The International Geophysical Year and International Geophysical Cooperation have accelerated this expansion.

1. Geomagnetic Surveys

1.1 *Three-Component Ground Surveys of the Dominion Observatory*

Observations for declination, inclination and total field intensity have been made at approximately sixty repeat stations reasonably well distributed in Canada. Additional observations for declination and horizontal field intensity have been made at more than one hundred locations, largely in the Maritime Provinces. All the results have been reduced and card-indexed for secular variation determinations. The magnetic results from ground surveys made between 1938 and 1947 have been submitted for publication (Madill and Clark, 1960). A further publication describing the field observations taken between 1948 and the present, is being prepared by Clark.

1.2 Three-Component Airborne Surveys of the Dominion Observatory

The three-component airborne magnetometer has been used each year. During 1957, some 25,000 miles of magnetic profiles were recorded along meridians approximately 100 miles apart over the provinces of Ontario and Quebec. In 1958, flight-lines totalling 21,000 miles were flown over the province of British Columbia and adjacent Pacific Ocean areas. In the third season, approximately 37,000 miles of flight-lines were flown in the Northwest Territories between latitudes 60° and 70° N., completing the coverage of Canada to latitude 70° N with an average flight-line spacing of between 50 and 100 miles, and at an average altitude of 10,000 feet. The results from all but the last survey have been reduced and card-indexed.

As a contribution to the International Geophysical Year, during 1958 the magnetometer was flown some 22,000 miles clockwise around the Pacific Ocean via Hawaii, the

Line Islands, the Society Islands, Samoa, Fiji, New Zealand, Australia, the Philippines, Japan, and the Aleutian Islands. The results from these flights have been supplied to two organizations which produce world magnetic charts. Although the magnetic field of the available aircraft was unusually large, and serious navigational errors are known to have occurred from time to time, there is an indication of the appearance of a centre of rapid change in the vertical field intensity in the central Pacific, and small systematic errors in the ocean values of declination presently depicted on charts.

The experience of this group in operating a serviceable and practicable instrument in a variety of climates and aircraft, together with their practical experience of the difficulties of azimuth reference, long-range navigation and so on, should be invaluable to the world-wide magnetic survey proposed for the near future. Serson and Whitham (1960) have described the Dominion Observatory equipment, its limitations and capabilities.

1.3 Total Intensity Airborne and Seaborne Surveys of the Geological Survey of Canada

Two hundred and thirty-two thousand line-miles of total intensity aeromagnetic surveys were flown in the period under review. To January 1, 1960 the total number of line-miles flown by the Geological Survey of Canada was 1,115,000.

In 1958, the Canso aircraft previously used was replaced by an Aero-Commander 680 aircraft. The fluxgate magnetometers are being replaced by proton-precession magnetometers.

An aeromagnetic survey of the southern part of the Gulf of St. Lawrence in 1958 represented the first large-scale venture in Canada of aeromagnetic assistance to submarine geology. This work is being expanded by towing seaborne magnetometers behind hydrographic ships operating in the Atlantic continental shelf area.

Christoffel, previously in New Zealand and now at the University of British Columbia, developed a seaborne nuclear precession magnetometer which was used on voyages between New Zealand and McMurdo Sound and in the Ross Sea.

2. Magnetic Charts and Maps

2.1 Isogonic Charts

An isogonic chart 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 compiled (Dawson, 1960) by the Dominion Observatory. This chart is noteworthy in that the results of all the three-component airborne surveys to and including that of 1958 have been used in constructing the isogonic lines. Several thousand requests for magnetic information were received from Canadian government mapping agencies and geophysical prospecting companies.

Whitham, Loomer and Dawson (1959) published a re-evaluation of the secular motion of the north magnetic dip-pole, concluding that it is moving approximately 6 miles per year slightly east of north. The position of the dip-pole adopted for use on Canadian and world magnetic charts, epoch 1960.0, is a compromise between independent Canadian and United States estimates, and is some 20 miles west of the admittedly uncertain Canadian estimate.

With the rapid accumulation of airborne magnetic data, even in the form of automatic averages over 20- to 25-km segments of the flight-lines, the compilation of charts is becoming

a much more formidable problem. It is hoped to minimize this by transferring the basic information to IBM punch cards as soon as possible, so that sorting and averaging of the data, estimation of secular variation and other tasks may be done by an electronic computer.

2.2 Total Intensity Map Sheets

During the review period, the Geological Survey of Canada has published three hundred and sixty-six aeromagnetic map-sheets depicting total intensity contours on a scale of one inch to one mile. By January 1, 1960, a total of 775 such maps had been published.

The semi-automatic geophysical map compiling machine devised by Morley and members of his staff, and built commercially, has been in satisfactory operation since 1958.

3. Magnetic Observations and Variation Stations

3.1 Magnetic Observatories

The four older Canadian magnetic observatories at Agincourt, Meanook, Baker Lake, and Resolute have been in continuous operation. During the I.G.Y. additional observatories equipped with standard-run photographic variometers and suitable equipment for base-line determinations, were in operation at Victoria, B.C. and Yellowknife, N.W.T. The Yellowknife observatory was closed after one year's operation, but it is planned to continue the operations at Victoria indefinitely. In addition the Defence Research Board operated a three-component standard-run photographic variometer at Churchill, Manitoba, during much of the period under review, and occasional base-line determinations were made there by Dominion Observatory personnel.

The equipment and facilities of the permanent magnetic observatories have been steadily improved; proton precession magnetometers are now used for total force in base-line determinations, and fluxgate recording magnetometers with automatic storm sensitivity reduction are in operation at all observatories.

3.2 Magnetic Observatory Publications

Thermo-Fax copies of the available magnetograms for the period of the I.G.Y. have been deposited with I.G.Y.—W.D.C., U.S. Coast and Geodetic Survey, Washington, U.S.A. During the I.G.Y. the magnetograms from the six primary observatories were read for special phenomena, and the tabulated information transmitted to Committee No. 10 of this Association. Disturbance (K) indices have been supplied to Committee No. 9 on a routine basis for Agincourt, Meanook, and Victoria. Q-indices for one year for Yellowknife have been measured and forwarded.

The results of magnetic observations at Agincourt and Meanook observatories for 1936-1937 have been published (Jackson, 1958), substantially in the form internationally recommended. Results for Agincourt Observatory for the years 1950 to 1954 inclusive have also been published (Ross 59a, 59b). Substantial progress has been made in the typing and preparation of further volumes of observatory publications.

A special effort is being made to expedite publication for the period of the I.G.Y. The results for Victoria 1957-1958 are in press (Caner and Loomer, 1960) and work on publications for Yellowknife, Baker Lake and Resolute well advanced by Loomer and

colleagues. More detailed publications for Meanook and Agincourt are under preparation by Madill and Cook, and Ross respectively.

A collection of three-hour range indices K for Agincourt, Meanook, Baker Lake, and Resolute has been published by Onhauser and Onhauser (1958).

3.3 Magnetic Variation Stations

For different periods during the I.G.Y. three-component magnetic records were obtained from chart-recording fluxgate magnetometers, produced commercially to a Dominion Observatory design (Serson, 1957) and operated at ten locations in Canada (Alert, Bird, Ennadai Lake, Flin Flon, Goose Bay, Ottawa, Saskatoon, Swift Current, The Pas and Winnipeg). During the I.G.C. variation stations continued in operation at Flin Flon, Ottawa, Saskatoon, and Swift Current. The records were, in general, obtained at a standard-run speed and with scale values of about 8 gammas per mm, and have been excellent for synoptic studies, range investigations and for storm recording.

The distribution of the variation stations and magnetic observatories in Canada during the I.G.Y. was such as to fit the cooperative synoptic program described by Meek (1959); they were operated, organized and equipped as a joint venture between the Canadian Department of Mines and Technical Surveys, the Defence Research Board and the University of Saskatchewan.

4. Developments in Magnetic Instruments

4.1 Developments at the Dominion Observatory

The three-component airborne magnetometer (Serson and Whitham, 1960) has been under constant development. Much of the stabilized platform has been rebuilt and new gyroscopes installed. Serson and Hannaford have succeeded in stabilizing the periscopic sextant in pitch, roll and azimuth, using signals from the stabilized platform, with a marked improvement in the accuracy of the azimuth reference and in navigational procedure.

The electrical recording magnetometer of the saturable core type developed by Serson (1957) was produced commercially, and has been successfully used for I.G.Y., and other studies. Such magnetometers have proved to be rugged, reliable in operation, flexible in use and logistically simple to install and support in isolated locations. Transistorized portable electrical magnetometers for three-component ground stations have been developed and a small number produced commercially to an Observatory design.

A number of proton precessional magnetometers have been built; the equipment of magnetic observatories with instruments of a standard design, utilizing the simplest possible amplifiers and making the maximum use of commercially available counting and timing units, is under way. A high-accuracy portable transistorized proton magnetometer has been built by Serson using a commercial transistorized time-interval meter. Using the basic principle that the field component along the axis of a suitable coil can be determined by a sequence of 3 measurements (no current, current on and current reversed), an experimental component proton magnetometer is under development. The coil axis alignment problems have been studied. Simple digital to analogue converters have been built by Niblett for recording station proton magnetometers. and Serson has devised a direct reading instrument.

Whitham (1960) has published an account of modern methods and techniques available for the measurement of geomagnetic elements. It should be noted that in principle it is now possible to envisage, in the not too distant future, a completely automatic observatory with digital processing of the data routine. When measurements are required of very low-amplitude transient phenomena with periods less than a few seconds, the rubidium vapour or some other type of magnetometer appears to be necessary.

4.2 Other Developments

A number of commercial developments should be noted. An airborne electron deflection magnetometer with a theoretical accuracy of ± 10 gammas has been flown by one mining company in its operations, and a self-levelling, self-orienting balance magnetometer mounted on gimbals in a silicone fluid has been developed for rapid mineral prospecting.

One or two university departments are developing proton precession magnetometers for various requirements, and equipment is being developed by Vozoff at the University of Alberta for the automatic recording of short-period magnetic and telluric events.

The techniques of the Pacific Naval Laboratory group investigating geomagnetic micropulsations have been further developed. The band-pass of some equipment has been extended, and the tape recording of data, for subsequent automatic analysis, is now routine.

5. Aeromagnetic Interpretation and Correlation Studies

A three-year study of the aeromagnetics in the Eastern Townships of southern Quebec has been concluded at the Geological Survey of Canada (MacLaren and LaRochelle, 1958). The purpose was to evaluate the usefulness of aeromagnetic data in correcting and extrapolating existing geological mapping under areas of cover and in interpreting regional structure. It was found in this area that second vertical derivative maps showed better correspondence with the geological mapping than did the total field maps. An analysis of the wide variation in susceptibility for individual rock types illustrates the difficulties in quantitative interpretation. MacLaren (1959a, 1959b) has completed correlation studies in several map areas of the Northwest Territories, using the aeromagnetic data to interpret the geology broadly.

Gregory, Bower and Morley (1960) have completed a study of reconnaissance aeromagnetic profiles in the Canadian Arctic Archipelago. A regional interpretation of an area of 45,000 square miles in the Great Plains area of Western Canada was undertaken jointly by the University of Alberta and the Geological Survey of Canada. Depth estimates were made and basement contours at 1,000-foot intervals were inferred. Tectonic features of the basement were interpreted and a number of faults observed on the adjacent exposed shield were traced under the sediments for several miles with the aid of the magnetic data (Garland and Bower, 1959). Bower (1959, 1960) has published other aeromagnetic interpretations.

At the University of British Columbia, Hall (1959) has developed equations for the magnetic field over a point dipole, a horizontal line of dipoles, a thin dipping sheet, a thick dipping sheet and a sloping step when both the directions of measurement and polarization are arbitrary. The field and its derivatives have been expressed in a reduced form which separates the parameters determining the anomaly shape from those determining the size.

The development of new measuring techniques, sometimes involving components other than those traditionally employed, and the growing realization of the importance of remanent magnetization have stimulated this study. In an earlier paper Hall (1958) discussed the use of least squares in magnetic and gravity interpretations. A regional study of northern Saskatchewan comparing the performance of methods of interpretation in Precambrian areas and adjacent sedimentary regions is under way by Hall.

Large-scale interpretations have been discussed by Hope (1959) who has presented a tentative description of the structure of the Arctic Ocean floor, in terms of recent data from Soviet sources and of representative Soviet theories of Arctic tectonics. Two theories of the so called great Arctic magnetic anomaly are compared. It may be related to an inter-platform geosynclinal corridor extending across the Arctic Ocean floor, or to ancient centres of crustal consolidation in the Canadian and central Siberian platforms.

6. Palaeomagnetic and Magnetic Rock-Property Studies

Dubois, LaRochelle and Black of the Geological Survey of Canada have measured the directions and intensities of magnetization of more than one thousand oriented samples from many different, and widely spaced formations in Canada. Both a spinner magnetometer, and the astatic magnetometer of the Dominion Observatory have been used. Pole positions have been calculated for many formations (Dubois, 57, 58a, 59a, b). Ages have been estimated from palaeomagnetic results, and some successful checks made against radioactive methods. Dubois (1958b, 1960) has used the method to assist in resolving geological structure and the relative ages of Proterozoic rock formations in the Lake Superior area. In addition, studies (Dubois, 1959b) of the Maritime rocks suggest there has been no relative rotation of New Brunswick and Newfoundland since Carboniferous time. LaRochelle (1960b) working on reversely polarized rocks from the Monteregian Hills in the Eastern Townships has developed a Curie point meter (LaRochelle, 1960a) for the investigation of possible magnetic self-reversals, and has devoted much effort to magnetic stability tests.

Carmichael (1958) at the University of Western Ontario has studied the remanent magnetization of the reversely polarized Allard Lake ilmenite deposits, using an astatic magnetometer. Declinations were scattered north and south with upward inclinations. The magnetization was found to be due to the hematite exsolution lamellae in the hematite-ilmenite mixture, with the direction being an average of the long axes of the lamellae. For this ore, therefore, forces aligning the crystal axes determine the directions of remanent magnetization, which is not necessarily related to the direction of the magnetic field in ancient times.

At the University of Toronto, experiments on the A.C. demagnetization of rocks have been performed by Chambers, Hood, and Strangway. The latter has built apparatus employing an inductive method to determine the variation of susceptibility of rocks with temperature. Hood has studied the rock magnetism of 750 samples from gabbro specimens from Bancroft, Ontario, and from the norite of the Sudbury basin. Strangway has sampled diabase dykes in the Canadian Shield, and found stable magnetization nearly parallel to the dyke, regardless of its age or strike, after removal of the unstable components of magnetization. The mechanism for this result has been studied experimentally.

At the Dominion Observatory, Roy has investigated the magnetic properties of drill cores from geological features of possible meteoritic origin. A search has been made for differential values of intensity supporting the idea of such features resulting from impact and subsequent heating and disturbance of the bedrock, but no definite results have been obtained to date. Apparatus for the heat treatment and A.C. demagnetization of rocks has been constructed, and samples of Palaeozoic and Proterozoic sandstones from the Maritime Provinces are being measured. Some of the equipment available is being described in a paper under preparation by Roy.

Scheidegger (1957, 1958) has suggested that a random walk model with an auto-correlation time of 30×10^6 years for continental drift approximately fits the pattern of continental drift deduced from palaeomagnetic data. It is possible the random forces are produced by convection currents with a half-life of the order of 30×10^6 years.

7. Magneto-telluric and Telluric Current Studies

Niblett and Sayn-Wittgenstein (1960) have published estimates of the electrical conductivity at depths of 10 to 100 km below Meanook magnetic observatory, using a modified form of Cagniard's theory and analysing the horizontal magnetic and telluric current components for periods from 40 to 1,000 seconds. The conductivity was found to decrease to about 80 km with an apparent increase by a factor of 10 between this depth and 100 to 120 km. At Meanook, the measurement of telluric currents has been continued on a routine basis and Cook is undertaking certain range correlation studies.

At the University of Alberta, Webster and Garland have considered the effect of depth to the Precambrian basement on magneto-telluric relationships, and model magneto-telluric studies are under way to supplement theoretical developments. Using electrodes installed in a dry oil well at Coleman, Alberta, the vertical component of earth currents has been measured on occasion. At the same site, during selected periods, the horizontal components and magnetic field variations have been recorded. The records are being studied by Garland; it appears certain that spurious results can be obtained from electric logs run during periods of magnetic disturbance.

The Pacific Naval Laboratory have made, on occasion, measurements of short-period earth currents as part of the investigations described in section 9.2 (*q.v.*). Plans are well advanced at the University of Alberta to cooperate in similar projects.

8. Research into the Main Geomagnetic Field and its Secular Variation

Chandrasekhar's theory of the stability of viscous flow of an electrically conducting fluid between coaxial rotating cylinders with perfectly conducting walls has been extended, by Niblett (1958) to include the case of non-conducting walls. The effect was found to reduce the critical Taylor numbers and increase the wave-lengths of the instability patterns by considerable amounts. Experimental work on the stability of Couette flow in an axial magnetic field has also been described.

Using the isomagnetic and isoporic charts for Canada, epoch 1955.0 the drift and decay contributions of the non-dipole field to the observed secular variation has been estimated

by Whitham (1958). The drift rates which produce the minimum residual secular variation were found to be unusually small. Confirmation of the small rate of westward drift of the non-dipole field in recent years in Canada was found by using the longitude displacement method applied to isomagnetic data only. Both methods show that one half of the world-wide secular variation can be produced by westward drift.

Since the last report, Hope (1957) has published a further paper discussing westward drift and cyclic secular variation, and concludes that the drift rotation of the terrestrial core must be zonal like that of the solar surface. Hope believes that the Bauer 480-year rotation is localized in the higher latitudes and has considered qualitatively the interactions which produce this motion, believed to be precessional. The cyclic evidence in secular variation has been presented in support of his ideas.

9. Studies of Magnetic Field Variations

The work described below is that currently reported in Canada under the field of geomagnetism. Many synoptic studies utilizing transient magnetic field changes as part of their material are in progress, and are reported by Forsyth in the companion National Report on Aeronomy.

9.1 Research at the Dominion Observatory

Madill is re-examining the subject of both long- and short-term predictions of the level of magnetic activity, with special reference to aeromagnetic survey problems in Western Canada.

Whitham, Loomer, and Niblett have used hourly ranges in the principal horizontal field component measured at the I.G.Y. network of observatories and variation stations to investigate the latitude distribution of magnetic activity, and the change in seasonal variation with latitude. Some confirmation of a narrow zone of enhanced magnetic activity near geomagnetic latitude 86° N was found, and some effort has been devoted to understanding this result. It is interesting to note that this partial confirmation of Nicolski's suggestion was possible only because of the I.G.Y. network. However a more detailed confirmation and morphological examination may now prove possible by using the logistic support and geophysical personnel of the newly formed Polar Continental Shelf project of the Canadian Department of Mines and Technical Surveys to obtain magnetograms from several of the northern Arctic Islands.

Niblett and Sayn-Wittgenstein have continued their analysis of a trial experiment using proton precession station magnetometers to measure the horizontal gradients of total field intensity. The correlation of transient field changes as a function of distance between stations and the level of disturbance is sought. A more detailed experiment with digital processing of the data is being planned by Niblett, Whitham and Serson.

Madill and Cook have carried on their researches into the micropulsations observed in Meanook magnetograms. Whitham and Loomer (1958) have described an investigation of one thousand pulsations with ranges greater than 3 gamma and periods between one and four minutes (largely Pt) observed on Canadian observatory standard-run magnetograms. The spatial coherence is qualitatively described. The unsatisfactory state of the

terminology and the art of measurement and selection were stressed. Inside the auroral zone, regular pulsations appear in general to have too short a period for this technique to be used. It is believed that magnetohydrodynamic waves in the upper parts of the ionosphere only can best explain the quasi-regular phenomena in this period range.

Pratap (1957) has reconsidered the dynamo-theory of solar flares.

9.2 Research into Micropulsations at the Pacific Naval Laboratory of the Defence Research Board

The investigations of geomagnetic micropulsations has continued. Duffus and Shand (1958) have reported on earlier observations at Albert Head, British Columbia, and Halifax Nova Scotia. The diurnal variation, direction and frequency spectrum of geomagnetic pulsations (Pc and Pt) in the period range of 10 to 1,000 seconds were determined. Duffus, Shand, Wright, Nasmyth and Jacobs (1959) have described a comparison of the observations of Pc's at a pair of stations only 25 miles apart. The ratios of the amplitudes of corresponding components were plotted as a function of period, and considerable and systematic variations from unity were found, particularly in the vertical field ratios. It was considered that the influence of the electrical conductivity of the sea was probably responsible.

This has been confirmed by an extended series of studies of the geographical variations using simultaneous observations at pairs of stations. The frequency response of the equipment has been extended to 3 cps and frequency modulated tape recording of the data is employed on occasion. Field stations have been occupied up to 500 miles away from Victoria and the sea, and comparisons made with data obtained from Borrego Springs in California, 900 miles to the south. In general the amplitude of vertical fluctuations has been found to decrease systematically as the distance increased from the sea and the unsymmetrical conductivity at the land-sea boundary. It has also been concluded that Pc activity is not related to local solar time, though this seems to be partially a matter of definition, and the properties throughout the frequency band do vary. The degree of regularity of micropulsations varies widely, further confusing precise definitions.

Two one-hour samples of tape records obtained at two inland stations near Ralston, Alberta, (in an area of uniform topography and geology) only $5\frac{1}{2}$ miles apart have been analysed on an electronic computer for energy spectra, coherence and phase displacement. The coherence for periods longer than 10 seconds was very high, but fell off rapidly for shorter periods because of noise content. The energy spectrum in the two samples was, not surprisingly, found to vary.

Conditions during magnetic storms have been examined, and an apparent shift of the energy spectrum to higher frequencies was noted. The presence of geomagnetic whistler-like phenomena has been reported (Duffus, Nasmyth, Shand, and Wright, 1958).

Longer period (1 to 2 minutes) Pt's have been recorded under quiet night-time magnetic conditions. These are often accompanied, or preceded, by shorter period fluctuations, typically of 2- to 6-second period (Duffus, Shand, and Wright, 1959). These longer period events have been traced on standard-run magnetograms over a large part of the earth.

The universities of Alberta and British Columbia have assisted in the field observations of the Pacific Naval Laboratory program.

9.3 Research at the University of British Columbia

Obayashi and Jacobs (1957) have published an account of an atmospheric dynamo theory which, with a constant wind system, can produce the observed geomagnetic variations both for quiet and disturbed conditions with a reasonable range of conductivity changes in the polar regions.

Obayashi and Jacobs (1958) have considered the theory of hydromagnetic oscillations of the earth's ionized outer atmosphere along geomagnetic lines of force. The observational evidence from world-wide pulsations yields the distribution of ionic density in the outer atmosphere beyond the ionosphere, and an ion density was deduced of $\sim 10^3$ per cm^3 at a distance of a few earth radii decreasing exponentially to ~ 5 per cm^3 in interplanetary space.

Sinno and Jacobs have carried on investigations of geomagnetic micropulsations, and and in particular have completed an analysis of Pc's using I.G.Y. data (Jacobs 1959a, and Jacobs and Sinno, 1960). It was found that the occurrence frequency of Pc's increased as the auroral zones were approached from lower latitudes and that the hour of maximum occurrence appears earlier at high latitude stations. The occurrence frequency of Pc's depends not only on local time, but in part on universal time. A similar analysis of Pt's is under way, investigating their relationships to bays, diurnal occurrence and geographical extent.

Jacobs (1959b) has published a general account of the morphology and theories of magnetic disturbance.

10. Research into the E.M. Method of Prospecting

10.1 Research at the University of Toronto

West has completed theoretical studies of the response of uniformly conducting and ideally disseminated bodies, including the response of a semi-infinite, infinitely conducting sheet in a dipolar field. Computation and model work on dyke structures and basic research on the electric properties of minerals, rocks, ores and soils is under way.

10.2 Research at the University of Western Ontario

Scale model experiments have been made by Surkan, Mason, and Uffen of the phase and amplitude electro-magnetic response of typical geological structures for several prospecting techniques, including airborne.

10.3 The Afmag Method

Ward (1959) and Ward, Cartier, Harvey, McLaughlin and Robinson (1958) have published accounts of the audio-frequency magnetometer, or Afmag, method of prospecting by using natural audio-frequency magnetic fields to investigate the electric properties of the earth's crust. The distortion of the normally horizontally polarized field by a conducting body is measured by search coil detectors (ground or airborne) at several discrete frequencies. Essentially the tilt of the plane of polarization is recorded simultaneously at two frequencies.

The method is claimed to have a greater penetration depth than conventional electromagnetic methods, but on occasion suffers somewhat from the lack of control over the signal strength. The possible extension of the method to sub-audio frequencies and deeper structures is under intensive study by Ward and collaborators.

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