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CONTENTS

67976-1½

CONTENTS (Cont'd)

CONTENTS (Cont'd)

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ILLUSTRATIONS

International Union of Geodesy and Geophysics

National Committee for Canada

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of the

National Research Council of Canada

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INTRODUCTION

This triennial report has been prepared for the Thirteenth General Assembly of the International Union of Geodesy and Geophysics (I.U.G.G.) on behalf of the Associate Committee on Geodesy and Geophysics which is the National Committee representing Canada in the International Union. It is an attempt to summarize the measurements of gravity and to review the research on gravity for the period from Jan. 1, 1960 to Dec. 31, 1962. Annual reports have been published in the Canadian Geophysical Bulletin (Garland, Editor) and similar triennial reports (Hamilton, 1960; Innes, 1957) have been prepared for previous General Assemblies.

The Dominion Observatory -- a Branch of the federal Department of Mines and Technical Surveys -- is responsible for the maintenance of relative gravity standards, for gravity control networks, and for regional gravity mapping. To support these major objectives work is undertaken in several allied fields such as instrument development, international gravity connections, and operation of a national gravity data centre. As the Observatory is primarily a research establishment there is, of course, emphasis on research on any worthy project that is possible. In the period under review gravity data have been used to assist in identifying fossil craters, to get the approximate thickness of ice on glaciers and snowfields and to assist in delineating various geological structures.

Several universities and research institutes undertake research in the application of gravity to specific problems from time to time. Within the last three years projects have either been completed or are still under way at the University of British Columbia, University of Alberta, Saskatchewan Research Council, University of Manitoba, University of Western Ontario, University of Toronto, Queen's University, McGill University, University of New Brunswick, and Nova Scotia Research Foundation. At the National Research Council in Ottawa an absolute determination of g has been completed.

Within the IUGG the measurement of gravity and the application of these measurements is of interest to many diverse and disparate groups. Traditionally the measurement of gravity has been considered an inherent part of the science of geodesy; thus Section IV of the meetings of the International Association of Geodesy (IAG) is entitled Gravimetry. Within this section progress in measurement of both absolute and relative gravity is discussed.

To coordinate the measurements of gravity throughout the world the International Gravity Commission was established as a standing

Commission of the IUGG and to carry out the policies established by the Commission a permanent office was set up in Paris known as the International Gravimetric Bureau (IGB). Both the Commission and the Bureau are concerned with the measurement of gravity and its application to problems of geodesy.

Inevitably there is an overlap of the interests of geodesy and geophysics. Knowledge of the physics of the earth contributes to understanding and evaluating the measurements of the size and shape of the earth and the knowledge of the size and shape, in turn, contributes to an understanding of the physics of the earth. The results of gravimetric investigations are of interest to the members of the International Association of Seismology and Physics of the Earth's Interior because analysis of gravity measurements provides a picture of the earth's mass distribution and this, in turn, is invaluable in studying the isostatic balance and the structure of the crust of the earth.

In addition, gravity techniques are becoming more and more widely used for detailed investigations of surface and near-surface features such as glaciers, snowfields, fossil craters, buried water courses, batholithic and other intrusions as well as many other geological features. This makes some aspects of gravity of interest to members of the International Association of Scientific Hydrology as well as to members of several organizations outside the IUGG such as those in geological and astronomical associations.

In view of these diverse applications of gravity it is useful to compile one national report that will include a summary of all the non-commercial activity in gravity in Canada for each three-year period. Reporters for other disciplines may then extract or abstract what they require for their association reports.

ABSOLUTE MEASUREMENTS AND CONNECTIONS TO FIRST ORDER WORLD STATIONS

Early in 1960 a long series of experiments to determine the absolute acceleration of gravity at the National Research Council in Ottawa were concluded. An abstract of the report on this work follows:

An Absolute Measurement of the Acceleration Due to Gravity at Ottawa (Preston-Thomas, Turnbull, Green, Dauphinee and Kalra, 1960).

'An apparatus for determining the absolute value of gravity by measuring the distances through which a rule falls in discrete time intervals is described. From the data associated with 64 drops with two non-magnetic stainless steel rules in vacuum, a value of g at the absolute gravity station at Ottawa of 980.6132 cm sec^2 with a possible error of $\pm$0.0015 cm sec^2 has been obtained. This value is 13.7 $\pm$ 2.0 milligal less than the Potsdam value at that position.'

The average correction to the Potsdam system indicated by this and other absolute determinations available to IAG Special Study Group 5 in 1960 was -12.8 $\pm$ 0.4 mgals.

In 1959 the Dominion Observatory bronze bi-pendulum apparatus was used to measure the gravity intervals between the First Order World (FOW) stations at Ottawa, Teddington, Paris, Rome and Bad Harzburg (Winter, Valliant and Hamilton, 1961). These measurements were incorporated in an adjustment of all available connections between Europe and North America that yielded a value for the Canadian National Reference Station (CNRS) of

$$g = 980.6197 \pm .0005 \text{ gals}$$

relative to the generally accepted value of 981.1804 gals for Bad Harzburg. This indicates that the adopted value of 980.6220 gals for the CNRS, hence all measurements in Canada, requires a correction of -2.3 $\pm$ 0.5 milligals to become consistent with other measurements in the Potsdam system.

If the best value of the acceleration of gravity in Canada in terms of the fundamental standards of length and time is required then the sum of the corrections listed above must be applied to any value observed relative to the CNRS -- that is, to any value published by the Dominion Observatory. This correction is -15.1 milligals with an uncertainty of the order of one milligal. It must be stressed that this is a provisional correction. There is no intention of abandoning either the Potsdam system or the Canadian reference system until many more measurements are available to improve the accuracy of the correction terms.

The absolute experiments at the National Research Council have not been resumed since completion of the observations published in 1960. The Dominion Observatory pendulum apparatus was dismantled at the end of 1959 and has not been used in the field since that time. As part of a post-graduate project at the University of Western Ontario, Mr. H.D. Valliant has built a completely new timing and recording system which uses an extremely accurate, portable frequency standard so that radio reception of WWV signals is no longer necessary for time interval measurements. The thermal sensing and control circuitry has been redesigned and an investigation of the effects of ambient temperature changes on the pendulums has been initiated.

NATIONAL PRIMARY NETWORK

During the last three years the National Primary Network of gravity control stations has been extended to the northern limits of the country as indicated in Fig. 1. Recent rapid growth of air services in Northern Canada has provided the transportation to make this possible and the advent of low-drift LaCoste and Romberg geodetic gravimeters has expedited the program greatly. Virtually all of the connections shown have been made with two instruments and many in the southern part of the country have been measured with seven or eight instruments. Adjustment of this network would be a relatively simple matter if the FOW stations at Ottawa, Vancouver and Fairbanks could be accepted without question. As it is, however, there is sufficient uncertainty in the gravity intervals between these stations that it will be necessary to adopt an interim arbitrary standard. A preliminary adjustment has already been made for that part of the network between Ottawa, Vancouver, Churchill and Fairbanks using the adopted value of the Ottawa - Washington base line (Innes, 1958) as a standard. Repeat measurements have been made where necessary so that now the stations within this region are internally consistent to within $\pm$ 0.2 mgal.

As formal publication of station descriptions tends to lag well behind physical changes, station description information is now being assembled in unpublished manuscript form with copies available on request only. Primary stations and excentres are assembled in one file and regional control stations in another. Details of these files are given below:

Primary stations and excentres

A system of excentres has been established for each primary station similar to that used by the IGB for FOW stations. It has been found to be more convenient, however, to show the connections and planimetric sketches on one page as illustrated in Fig. 2. At the end of 1962 a file containing the excentres for all primary stations west of Ottawa was available (Hamilton and Winter, 1962) and a similar file for stations east of Ottawa was in preparation.

Regional gravity control stations

To supplement the primary stations discussed above, additional control stations are established (Fig. 1) in conjunction with each regional gravity mapping program (Fig. 4). Some of these are temporary and no attempt is made to describe them. Many others, in relatively stable surroundings, are described and put on file for use on resurveys or special surveys of the area in the future. The regions for which these are available and the approximate total in each region are shown on Fig. 1. The number that have been added in the last three years is shown in brackets in each region. In the southern part of the country these stations are of the order of 30 miles apart whereas in the north they are 100 to 150 miles apart.

GRAVITY DATA PROCESSING SYSTEM OF THE DOMINION OBSERVATORY

During the last four years a system for automatic processing of gravity data by digital computer has been evolving at the Dominion Observatory. Initially a program was written for use on an IBM 650 computer which merely carried out the arithmetic operations previously done by desk calculator. Numerous revisions have been made until, at the present time, a fully automatic program is in use on an IBM 1620 computer. A comprehensive report on this program has been submitted for publication in the Bulletin Geodesique (Tanner, in press).

Primarily the program is designed to process data from the field surveys conducted by the Dominion Observatory as described under Regional Gravity Mapping below. Without going into details it is sufficient to say that the field observations are transferred directly to cards and the program sorts and classifies the observations, computes the anomalies, and punches out the principal facts on cards in the format shown in Figure 3. Most of the pertinent features of the output are apparent from the card format. An explanation for some of the special codes follows:

Map Sheet - This is the number of the National Topographic System map on which the station is located. These map sheets have the same boundaries as ICAO. 1:1,000,000 World Aeronautical Charts.

Datum fact and elev. fact - The elevation factor is an assessment of the accuracy of the station relative to adjacent stations and the datum factor is an assessment of the accuracy of the elevation datum relative to mean sea level. The code used to classify accuracies is listed below:

Datum Factor	Elevation Factor
1. Spirit level	1. ± 3 feet
2. Radar altimeter or other altimeter	2. ± 10 feet
3. Arbitrary	3. ± 25 feet
	4. ± 100 feet
	5. greater than ± 100 feet (includes estimations)

Coord. fact. - This code identifies the source of the coordinates and hence gives an indication of their quality.

1. Scaled from 1:25,000 map
2. " " 1:50,000 map
3. " " 1:125,000 map
4. " " 1:250,000 map
5. " " 1:500,000 map
6. Instrument means - Decca, star observations, etc.
7. Dead reckoning
8. Other sources

I or W - This identifies measurements on ice or water.

I or W fact. - This gives an assessment of the accuracy of ice thickness or water depth and is coded as follows:

1. ± 3 feet
2. ± 10 feet
3. ± 25 feet
4. ± 100 feet
5. greater than 100 feet (includes estimations)

Adj. - This is a three digit code to identify the datum to which the control stations are referred. Two of the codes currently in use follow:

1-59 Central and northern Quebec
1-62 Western Canada

Sea state. - This space will be used to describe the roughness of the sea at the time sea-surface measurements are made.

GRAVITY AT SEA

Underwater measurements

A program of underwater measurements by the Dominion Observatory was initiated in 1961 with a traverse across Hudson Bay (Fig. 5) and continued in 1962 in the southern part of the Gulf of St. Lawrence. Using ships chartered by the Marine Sciences Branch of the Department of Mines and Technical Surveys stations were observed at intervals as weather permitted in 1961 and at approximately eight mile intervals in 1962. A 1200-foot multiconductor cable was used to lower and raise the LaCoste and Romberg underwater gravimeter as well as to relay information on the levelling, clamping, heating and reading from the instrument to the control console on the ship.

The gravimeter is of the unstable type with high damping and is adjusted to have an infinite period. With this adjustment the rate of change of beam position is proportional to the difference between the torque exerted on the beam due to spring tension and the torque due to gravity. In the conventional land meter the instrument is set in a stable configuration and the beam position is the only important parameter. The beam motion is displayed graphically on the console. From the graph the beam velocity can be found and this, along with the dial reading, yields the gravimeter observation. This method of reading beam motion makes observations possible even when the instrument is unsteady due to seismicity or water movements. Repeat readings indicate that the reading accuracy is of the order of 0.1 or 0.2 mgal. In 1961 position was determined from dead reckoning but in 1962 Decca coordinates were available for all stations.

Measurements on sea ice

On the Polar Continental Shelf Project stations have been observed on the ice of the Arctic Ocean northwest of Borden and Ellef Ringnes Islands, as indicated on Fig. 4. On this survey a large helicopter was used to transport the gravity observer and the hydrographer together so that gravity observations and depth soundings could be made simultaneously. A specially designed LaCoste and Romberg ice gravimeter was used. This instrument is similar in principle to the underwater meter described above; it is also a highly-damped infinite-period type with beam motion recorded graphically but it does not have automatic levelling or remote recording facilities. An abstract of a report on this project follows:

> Gravity Anomalies Over the Polar Continental Shelf (Weber, in press).
>
> 'As part of the Polar Continental Shelf Project a gravity survey was carried out over the continental shelf north of the Sverdrup Islands. Using Decca navigation 350 stations were observed, the outermost stations being located over the continental slope some 250 kms from shore. A free air anomaly map and a bathymetric chart are presented. A very large positive anomaly feature of 120 milligals running parallel to the continental slope was discovered. The anomaly is discussed and interpreted as the effect of the transition of the crust from continental to oceanic domain.'

Development of vibration gravimeter

A vibrating string gravimeter constructed entirely of quartz has been developed at the Dominion Observatory by Mr. D.R. Bower. A phase-locked tracking system has been designed to correct for the nonlinear response inherent in vibrating string instruments and, in addition, to smooth the effects of extraneous accelerations. Methods for isolating the sensitive quartz assembly from the effects of accelerations due to shock are presently being studied.

The Second-order Errors of Sea-surface Gravity Measurements (Bower and Watt, 1963).

Abstract: 'A theoretical study of the effect of a continuous acceleration spectrum on the performance of a sea gravimeter is made. When a continuous rather than a discrete spectrum is assumed, second-order errors due to acceleration product terms become more complex. In particular, the second-order correction which must be applied to the reading of a gimbal-mounted gravimeter is disturbed from the constant value previously found assuming sinusoidal ship motion. This disturbance is in the form of very-long-period noise which has, in a typical case, a r.m.s. value one seventh of the constant value. It is shown also that very-long-period noise is present in the reading of a vertically stablized gravimeter due to cross-coupling effect and that it occurs whether or not the beam displacement and the horizontal accelerations are correlated. Finally the possibility of errors occurring due to nonlinear ship response is discussed.'

REGIONAL GRAVITY MAPPING BY THE DOMINION OBSERVATORY

A program of regional gravity mapping is now fully underway at the Dominion Observatory. Maps at the scale of 1:500,000 are being published in a new series known as the Gravity Map Series of the Dominion Observatory. As indicated in Fig. 4, four map sheets have been published, ten are in press, and several are in the compilation stage; field observations for several map sheets are completed each year. Existing 1:500,000 maps are used as a base map being shown in neutral grey, water areas in light blue and gravity data in red. The Bouguer anomaly is shown for each station and contours are drawn at five milligal intervals. A report describing the quality of the data, correlation with geology and a preliminary interpretation accompanies each group of maps. In some special cases, such as the Arctic Islands, preliminary black and white prints are being issued.

Observations for regional mapping are taken at intervals of nine miles (15 kilometres) or less. Virtually all of these regional readings are taken with Worden Gravimeters. The mode of transportation varies with the region. Road transportation is used wherever possible but for the most part the areas accessible by road were completed several years ago. Float-equipped aircraft are used where lakes are plentiful and helicopters are used in the Arctic and in other areas where necessary.

Progress by areas during the past three years is summarized below

Region	Area Square Miles	Number of Regional Station
Quebec and Labrador	160,000	3,000
Baffin Island	200,000	4,000
Arctic Islands (Polar Continental Shelf)	140,000	2,000
Northern Saskatchewan and Alberta	120,000	2,500
Northwest Territories (Muskox Project)	40,000	500
Prairie Provinces (South of 54° N)	75,000	1,800
TOTAL:	735,000	13,800

Abstracts of the reports published and in press follow.

General Characteristics of the Gravity Field in West Central Quebec (Tanner, 1961).

'The results of approximately 900 regional gravity stations established during 1958 in the Province of Quebec adjacent to Hudson and James Bay are presented in the form of four Bouguer anomaly maps. The Bouguer anomaly field throughout the area is relatively flat and the principal variations can be related to surface geology. Areas underlain by lower density granitic masses are associated with negative anomalies whereas in those regions underlain by gneisses and schists and, locally, altered basic volcanic rocks the anomalies are generally higher. The mean Bouguer anomaly for the four maps, -55 milligals, in relation to a mean station elevation of 900 feet suggests that the region is over-compensated isostatically which may be the expression of crustal depression during the Pleistocene period.'

Regional Gravity Survey of the Sverdrup Islands and Vicinity (Sobczak, in press).

'Five profiles are used to analyse the major features of the Bouguer anomaly field. The observations are correlated with magnetic and geological information and the interpretation of the gravity data based on measured densities and densities computed from seismic velocities. On the basis of a density contrast of 0.14 gm/cc and an anomaly change of 63 milligals over a distance of 120 miles, the calculations indicate depths to basement varying from 6,800 feet near Isachsen to possibly 42,000 feet near the axis of the Sverdrup Basin. A broad positive Bouguer anomaly over Peary Channel is partly attributed to a corresponding broad lens of basic rocks extending from an outcrop on the Fay Islands. A sharp negative anomaly under Peary Channel north of the Dumbbell gypsum dome suggests a similar but larger submerged dome.'

Preliminary Results of Gravity Surveys in the Queen Elizabeth Islands (Sobczak, Weber, Goodacre and Bisson, in press).

'The data of some 3250 gravity stations over the Queen Elizabeth Islands and the adjoining polar continental shelf has been compiled. The results are presented in four Bouguer anomaly contour maps, and the anomalies are briefly discussed.'

GRAVITY IN GLACIOLOGICAL INVESTIGATIONS

In the study of glaciers and snowfields gravity measurements can be used to contour the lower surface of the ice mass. For the best results some control measurements such as bore holes or seismic depth determinations are needed but where the regional gravity field is not highly anomalous good approximations of the ice thickness can be made solely from the gravity data. The glaciers and icecaps on which gravity measurements have been made or published during the period under review are shown on Fig. 5 and discussed briefly below.

Athabasca Glacier, B.C.

In 1959 teams from the Universities of British Columbia and

Alberta carried out gravity and seismic surveys over the lower part of the Athabasca Glacier. Depth determinations by gravitational, seismic and electrical resistivity methods were reasonably consistent. A report on this project by Mr. E.R. Kanasewich has been submitted to the Journal of Glaciology.

Salmon Glacier, B.C.

An abstract of a paper on this glacier follows:

Gravity Measurements on the Salmon Glacier and Adjoining Snowfield, British Columbia, Canada (Russell, Jacobs and Grant, 1960).

'An account is given of a detailed gravity survey carried out on the Salmon Glacier and the adjoining snowfield. The reduction of the data is complicated by the extreme irregularity of the terrain and by the fact that the structure of the glacier and the locations of the stations are time dependent. Maps show the Bouguer anomalies, and two profiles are drawn across the glacier and one along its length. The accuracy of the results is discussed in detail; it is concluded that gravity measurements alone can give a very good indication of the shape of a deep-valley glacier and also its approximate depth. Other independent data are necessary to determine its precise thickness.'

Kaskawulsh and Hubbard Glaciers, Yukon Territory.

Gravity and seismic surveys were undertaken in 1962 by an Arctic Institute of North America expedition to investigate the form of the rock divide between the Kaskawulsh and Hubbard glaciers. The geophysical work was performed by students from McGill University and the University of Alberta.

Penny and Barnes Icecaps, Baffin Island, N.W.T.

In conjunction with the regional gravity mapping of Baffin Island by the Dominion Observatory a first order traverse was surveyed across the Penny Icecap and also across the Barnes Icecap in 1962. Several ice thickness measurements were made by explosion seismology and gravity readings were taken at frequent intervals to assist in interpolating for the thickness of ice along the traverse. Permanent markers were set in place on the Penny Icecap so that the gravity stations can be reoccupied in a few years to determine quickly whether there is an increase or decrease in the total mass of ice and snow.

Devon Island Snowfield, N.W.T.

During the summer of 1962 a gravity survey was carried out on the Devon Island Icecap by members of a party organized by the Arctic Institute of North America. To investigate ice thickness fifty gravity observations were taken along an 80 kilometer traverse from 75° 35′ N, 83° 30′ W on the north edge of the ice, to 75° 20′ N, 82° 30′ W, approximately the highest point of the icecap, and thence to 75° 00′ N, 83° 30′ W on the south edge. It is anticipated that the error in ice thickness determined from these observations will be less than ten per cent.

Meighen Island Icecap, N.W.T.

During the summer of 1960, in conjunction with the Polar Continental Shelf Project gravity observations were made at 156 stations on the Meighen Island Icecap by a party from the Dominion Observatory (Hornal, 1962). Bouguer anomalies have been computed for these stations and, by removing the regional trend, the residual anomalies attributable to the effect of the ice have been found. From these residual anomalies, using a density of 0.9 gm/cm^3 for ice and 2.39 gm/cm^3 for the underlying sediments the thickness of the ice has been estimated. These results show that the maximum thickness of 500 feet occurs near the southern edge and that the cap thins out to about 100 feet over its northern half.

Axel Heiberg, N.W.T.

In 1959 and 1960 a number of gravity measurements were made to investigate the thickness of ice on the McGill Icecap (unofficial name), the White Glacier and the Thompson Glacier (Becker, 1961). An analysis of these results is nearing completion.

Gilman Glacier and adjoining icecap, Ellesmere Island, N.W.T.

Two papers have been published on the results of geophysical surveys in this region (Weber, 1960; and Weber, Sandstrom and Arnold, 1960).

Abstract of the first paper follows:

Comparison of Gravitational and Seismic Depth Determinations on the Gilman Glacier and Adjoining Icecap in Northern Ellesmere Island (Weber, 1960).

'During the summers of 1957 and 1958 twelve bedrock profiles on the Gilman Glacier and on the icecap between Gilman Glacier and Mount Oxford were determined from seismic reflections. During the second field season more than 200 gravity stations were established over the same general area. The regional Bouguer anomaly was calculated from the known ice thickness at a few selected locations along the seismic profiles, and was then extrapolated for the whole area. With this information and with assumed specific gravities of ice and bedrock of 0.9 and 2.71 respectively, the ice thickness was calculated from the gravity measurements. Agreement between the bedrock profiles as determined by the two methods was very close. It is concluded that a gravity survey, when supplemented by a few seismic soundings, can give a good indication of the shape of the bedrock and the ice thickness.'

GRAVITY IN FOSSIL CRATER INVESTIGATIONS

Several detailed gravity surveys have been made as part of an investigation by the Dominion Observatory to determine whether certain circular topographic features were formed by the impact and explosion of meteorites during the early history of the earth or whether they have been formed by processes originating from within the earth. When a negative gravity anomaly is found for these features it is evidence that the feature may be underlain by low density brecciated material indicative of an explosive origin. A brief discussion of the circular features identified on Fig. 5 follows:

Holleford, Brent and Deep Bay

Gravity surveys followed by geological and structural studies and by diamond drilling have led to the conclusion that all of these features were formed by a surface explosion and the most likely causes of these explosions were the impacts of meteorites. (Beals, Innes and Rottenberg, 1960, in press). An abstract of one of the several papers on these features follows:

The Use of Gravity Methods to Study the Underground Structure and Impact Energy of Meteorite Craters (Innes, 1961).

'Gravity data have been used to calculate the mass deficiency and hence the amount of shattered rock under the Deep Bay, Brent and Holleford craters. The results show good agreement with the crater model computed by Rottenberg as combined with the depth/diameter ratios of Baldwin for meteorite impact craters. The zone of complete rupture is shown to extend to a depth of approximately one-third of the crater's diameter, and impact energy values derived from energy of crushing, are 6.5×10^{23} ergs, 2.1×10^{24} ergs, and 8.7×10^{25} ergs for Holleford, Brent and Deep Bay, respectively.'

New Quebec

Due to its remote location this feature has not yet been the subject of as intensive an investigation as the three mentioned above. However, as it was formed in relatively recent geological time a comprehensive investigation of it will undoubtedly contribute significantly to the understanding of crater formation. As part of this investigation, in the spring of 1961, a detailed gravity survey and depth soundings were made from the ice surface of the lake which occupies this crater.

Clearwater Lakes

Preliminary gravity and topographical studies of these two large adjoining lakes were carried out by the Dominion Observatory during the winter of 1961 and a geological examination of the shore line and islands in the west lake was carried out during the summer of 1962. At the end of the period under review a more detailed gravity study and observations of the vertical magnetic intensity along two diametrical traverses was being made. The results of these investigations are being prepared for publication by M.R. Dence, L.W. Sobczak and M.J.S. Innes.

West Hawk Lake

An abstract of a report on this feature follows.

Evidence in Support of a Meteoritic Origin for West Hawk Lake, Manitoba, Canada. (Halliday and Griffin).

'West Hawk Lake in southeastern Manitoba is approximately circular with a present shoreline 11,700 feet in diameter and water depths up to 365 feet. Gravity readings from the lake ice indicate a residual negative anomaly of 6 milligals associated with the feature. The lake is not closely related to the local geology and an origin due to meteorite impact appears reasonable. An original rim diameter of 12,000 feet, modified by glaciation and erosion, is suggested, from which about 660 feet of sedimentary deposits are expected near the centre, underlain by a thick layer of breccia. It is hoped to confirm these predictions in the future by diamond drilling techniques.'

GRAVITY IN STUDIES OF GEOLOGICAL STRUCTURE

The requirements for gravity data to assist in delineating geological structure in Canada have increased steadily during the last few years. Several new projects have been undertaken and several continuing projects have been studied in more detail as new information became available to assist in interpreting the observations. The locations of the features that have received attention during the period under review are shown on Figure 5; each one is discussed briefly below starting with features at the southeast of the country and continuing towards the west and north.

Nova Scotia

During the past three summers 3300 relative gravity observations have been made over the Carboniferous sediments in Nova Scotia by parties from the Nova Scotia Research Foundation under the direction of Prof. J.E. Blanchard. These observations have been made at intervals of 1000 feet along roads and trails. Elevations have been determined to a tenth of a foot and Bouguer anomaly maps contoured to two-tenths of a milligal are in preparation. These observations are tied to the Dominion Observatory's gravity network. This program represents a continuation of a program begun in 1952.

Mount Albert, Quebec

The regional gravity survey of Gaspe (Tanner and Uffen, 1959) while indicating a gravity high near the Mount Albert ultrabasic mass, did not completely cover the intrusion. As part of a program to locate promising drill sites for the International Upper Mantle Project, a detailed network of gravity stations was established over the body in 1961 by a party from the Dominion Observatory.

Eastern Townships, Quebec

A detailed gravity survey of this area has been under way for several years. An abstract of a report on this work follows.

> Gravity in the Eastern Townships of Quebec (Fitzpatrick, in preparation).
>
> 'Anomalous values of gravity in the Eastern Townships of Quebec range from -60 to +55 milligals. The most significant feature is a long linear positive anomaly paralleling and coinciding with, to a large extent, the axis of the Sutton Mountain anticlinorium. This anomaly is almost certain to be due to a major ultramafic intrusion which may represent an upwarped section of the mantle. Calculations show that this ultramafic material rises to within 10 kilometres of the surface near the town of Richmond, Quebec.'

Anstruther, Ontario

The Anstruther granitic intrusion, located near Bancroft, Ontario, is one of four intrusive features outcropping along an approximate north-south axis. In cooperation with the Geological Survey of Canada a party from the Dominion Observatory carried out a detailed gravimetric survey near the batholith and made measurements throughout the surrounding region in 1961.

Southwestern Ontario

At the University of Western Ontario a study has been made of the effects of variations in the bedrock topography and depths of overburden on gravity anomalies associated with buried limestone reefs. A hammer seismograph was used to determine depths of the overburden.

Kapuskasing High

During the summers of 1961 and 1962 a total of 360 stations has been observed by a party from the University of Manitoba to delineate in more detail the structures of this high anomaly first identified and interpreted by the Dominion Observatory. As the high cannot be correlated with the density of surface samples a deep-seated interpretation must be sought. Model studies indicate that moderate warps in the Conrad or Conrad and Mohorovicic discontinuities could produce anomalies similar to those observed. Correlation with geology and with the magnetic anomaly pattern was discussed in a paper presented to the Canadian Institute of Mining and Metallurgy in April 1962 (Brisbin and Wilson).

Red Lake Area

A gravity traverse over the greenstone belt in the Red Lake district was made in 1962 by a party from the University of Toronto in an attempt to discover the outline of the formation at depth.

Kenora Area

A gravity survey of the Lake of the Woods area is being carried out by a party from the University of Manitoba. Some 200 stations at one-mile intervals had been established by the end of 1962. The primary objectives of this survey are to determine the dips of the granite-greenstone contacts along the boundaries of the greenstone belt. The Bouguer anomaly map and model studies that have been prepared from the field work already completed will be extended as field work continues.

Churchill-Superior Boundary

Investigation of the large negative anomaly, which coincides with the boundary between the Churchill and Superior geological provinces of the Canadian Shield and the associated Nelson River High has been continued by parties from the University of Manitoba during the period under review. Some 500 gravity stations had been established prior to the publication of two reports by Wilson and Brisbin (1961 and 1962) on their geological and geophysical investigations of the area and 135 stations have been established since these reports went to press.

Coronation Mine

A gravity survey of the surface and underground workings of this mine was completed by a party from the University of Manitoba as part of a "Comprehensive Study of an Ore Deposit" for the National Advisory Committee for Research in the Geological Sciences and the data is being analysed.

Kindersley, Saskatchewan

As part of an intensive search for underground water sources in the Prairie Provinces the use of gravity methods has been investigated in the Kindersely - South Saskatchewan River area by the Saskatchewan Research Council. An abstract of a paper on this work follows.

The Gravimeter in Studies of Buried Valleys (Hall and Hajnal, 1962).

'In glaciated areas, variation in density and thickness of the drift or of members within it is often an important cause of gravity anomalies. This can be utilized whenever the drift is the principal object of attention, such as in prospecting for ground water. Trends of gravity lows near Kindersley, Saskatchewan, some with amplitude of one milligal, appear to be connected with buried valleys formerly occupied by the South Saskatchewan River and its tributaries. Calculation from detailed gravimeter traverses and comparison with borehole samples give estimates of the thickness and density contrasts of the fill in the valleys. These indicate a low-density sand section with a thickness of up to 250 feet and a density contrast of 0.27 gm/cc for the buried valley of the South Saskatchewan River; and a low density silt section with a thickness of up to 400 feet and a density contrast of 0.25 to 0.35 gm/cc for a buried tributary valley. Density measurements indicate that contrasts within the drift can be as large as those between bedrock and drift. It is thus possible to detect buried valleys which have been cut entirely into drift, as well as those cut into bedrock.'

Rocky Mountain Trench

An abstract of a paper on this area follows.

Gravity Measurements over the Southern Rocky Mountain Trench Area of British Columbia (Garland, Kanasewick and Thompson, 1961).

'A series of negative anomalies along the southern part of the Rocky Mountain Trench has been interpreted to be the effect of relatively deep basins in the trench floor. These are apparently filled with light material and separated from each other by regions of only thin cover over bedrock of normal density. The pattern obtained is very suggestive of a system of longitudinal and transverse faults, and the gravity field is therefore consistent with the theory that the trench, in this vicinity, was produced chiefly by down-faulting.'

Vancouver Island

An abstract of a doctoral thesis on this area follows.

The Structure of the Earth's Crust in the Vicinity of Vancouver Island from Seismic and Gravity Observations (White 1962).

'A seismic explosion program has been carried out in the Vancouver Island - Strait of Georgia area of Western Canada. The program included a relatively intensive survey in the Strait of Georgia between Campbell River and the south end of Texada Island, as well as a number of longer range refraction lines extending from Kelsey Bay along the coast as far south as northern California, and east through the mountains to a distance of 700 kms. Gravity readings were obtained at intervals of about ten kms along the east coast of Vancouver Island as well as for a number of east-west traverses. Readings were also obtained for a few locations on the British Columbia mainland. Except for a marked positive trend in the Victoria area, the regional value of the Bouguer anomaly for the Vancouver Island area is nearly zero.

The average structure for the area, derived from the seismic refraction observations consists of a layer of volcanic and granitic strata less than five km in thickness, and an intermediate layer with a constant velocity for compressional waves of 6.66 km/sec., 46 km thick. A velocity of about 7.7 km/sec. for the mantle has been observed along unreversed refraction lines, both along the coast and east through the mountains. Interpretation of the refraction observations has been based mainly on first arrival phases. The observed regional gravity anomaly is compatible with the crustal model obtained from the seismic results.'

Muskox Complex

As part of Canada's participation in the International Upper Mantle Project a large ultrabasic intrusion some 75 miles long varying in width from 1000 feet at the southern end to five miles at the northern end is being investigated by the Department of Mines and Technical Surveys. In a cooperative project with the Geological Survey of Canada to select suitable deep drilling sites, a party from the Dominion Observatory established some 1800 gravity stations in the immediate vicinity of this intrusion and 500 more in the surrounding region (Fig. 5).

Gypsum Domes

In cooperation with the Polar Continental Shelf Project two large gypsum diapirs, termed the Isachsen and Dumbbell domes, have been surveyed by a party from the Dominion Observatory. Negative Bouguer anomalies of the order of 20 to 25 milligals respectively have been found (Sobczak, in press) but a full interpretation is not yet available.

Northern Ellesmere Island, N.W.T.

In conjunction with the Polar Continental Shelf Project two gravity profiles were observed by a party from the Dominion Observatory between Ellesmere Island and Greenland over a zone of anomalous conductivity that was discovered by the Geomagnetic Division (Whitham and Andersen, 1962).

GRAVITY IN GEODETIC INVESTIGATIONS

With the rapid extension of regional gravity mapping in Canada occurring at the same time as the availability of electronic digital computers extensive geodetic investigations using gravity data can now be undertaken that would have been impossible just a few years ago. Two abstracts are given below as well as a brief outline of another project that is still underway.

A Study of the Geophysical and Geodetic Implications of Gravity Data for Canada (Shimazu, 1962)

'Making use of Bouguer anomalies and corresponding surface elevations in Canada, investigations have been made of the physical state of the earth's crust, the distribution of isostatic anomalies, undulations of the crust-mantle boundary, deflections from the vertical and undulations of geoidal heights. A modification of Tsuboi's method -- which assumes that a variation in the gravity is caused by the anomalous mass distributions at the base of the crust -- is used in this study and computational methods are outlined in Section I. The densities of the crust and the subterranean mantle are assumed to be 2.67 and 3.27 gm/cm^3 respectively. All the geophysical and geodetic quantities mentioned above can be obtained in a form of matrix products $Y_{ab} = \sum_i \sum_j X_{ij} \cdot \phi_{a-i,\, b-j}$ where $\phi_{a-i,\, b-j}$ is a response function to convert the given data X_{ij} (gravity anomaly or elevation) into Y_{ab}.

Section II consists of two-dimensional analyses carried out for three profile sections: the Canadian Shield, the Transcontinental section from the Pacific to the Atlantic coast, and the Cordillera. The grid interval for the gravity and elevation data has a range varying from 51.5 km to 210 km for these three sections, and thus the local variations of gravity and elevation with wave-lengths shorter than twice the grid interval (103 to 420 km) play no important part in the results. Section III is the three-dimensional analysis for the rectangular area bounded by longitudes 90° and 113° W and latitudes 49° and 62° N of Western Canada. The grid interval is 72 km and the total number of grid points for the Bouguer anomaly is 21 x 21. To obtain the response functions ϕ_{ij} and matrix products $Y_{ab} = \sum_i \sum_j X_{ij} \cdot \phi_{a-i,\, b-j}$ numerical calculations were carried out using a digital computer.

A brief interpretation of the results is presented. The average crustal thicknesses which are derived from the condition Σ (isostatic gravity anomaly)^2 = minimum, were found to be 36.4 km and 48 km for the Canadian Shield and the southern Cordillera respectively. The Cordillera and Shield regions are isostatically over-compensated while for the central Prairie regions the opposite condition is true. In the area where the three-dimensional analysis is carried out the isostatic gravity anomalies range from -30 mgals in the north, to +20 mgals in the south. The deflections of the vertical do not exceed 4 seconds in the whole area with corresponding undulations of the geoidal heights varying from +5 m in the south to -8 in the north. The effect of the Mesozoic or younger sediments near the surface of the prairie region upon the over-all gravity field appear to be negligible.'

Gravimetric Deflections of the Vertical by Digital Computer (Nagy, in press).

'A digital computer program has been developed to calculate plumb-line deflections from gravity data. A region in Western Quebec 1,200 x 1,200 km for which free-air anomalies were available was subdivided into units of 50 x 50 km. With n denoting the number of points per unit, each unit was represented by one gravity anomaly calculated as an average in cases where $0 \leq n < 6$ and where $n > 50$. For $6 \leq n \leq 50$ the integral mean, obtained from a fitted surface of second order in two variables, was used.

Weighting functions were derived for and calculations were done in the rectangular plane coordinate system. For units with sufficient points for surface fitting, the contributions to the deflection components at the centre of the unit from within the unit itself were computed first, and then the effect of the outer region was added. The contributions from the outer region were obtained as the sum of the products of gravity anomalies and weighting coefficients over all units. The computations were repeated with three different origins in order to analyse the effect of the change in the number of points and the point distribution within the 50 x 50 km units. This analysis shows that non-uniform point distribution may seriously distort the fitted surface, giving erroneous values for the horizontal gradients and hence for the contribution to the deflection components at the centre from within the unit element.

The program solves for the gravimetric deflections relative to the origin. To make the computed gravimetric deflections comparable with astro-geodetic deflection it was necessary to transform the astro-geodetic deflections from Clarke's spheroid to the International Ellipsoid and to add a constant term to all the gravimetric deflections. This constant term, representing the effect from beyond the region of integration, is the difference between the astro-geodetic and gravimetric deflections at the origin. A visual comparison of the plotted deflections shows generally good agreement both in direction and magnitude, indicating that the choice of weighting function, grid distance, and order of fitted surface was suitable. The accuracy of the astro-geodetic and gravimetric deflections is estimated at ± 1 and ± 2 seconds of arc respectively.'

Vertical deflections in New Brunswick

As part of an investigation of the geoid in the Maritimes a free air anomaly map of the Fredericton area has been compiled at the University of New Brunswick using published data as well as measurements made during 1962 in cooperation with the Dominion Observatory. Deflections of the vertical at four points will be computed from this data by the templet method for the near region and by electronic computer using mean free air anomalies as published by Heiskanen for more remote regions. A comparison between the gravimetric and astronomic deflections is being made. This work will be included in a thesis by E. Derenyi working under the direction of Prof. G. Konecny.

OTHER INVESTIGATIONS

Bouguer Gravity Corrections Using a Variable Density (Grant and Elsaharty, 1962).

'The principle of density profiling as a means of determining Bouguer densities is studied with a view to extending it to include all of the data in a survey. It is regarded as an endeavour to minimize the correlation between local gravity anomalies and topography, and as such it can be handled mathematically by the method of least squares. In the general case this leads to a variable Bouguer density which can be mapped and contoured. In a worked example, the correspondence between this function and the known geology appears to be good, and indicates that Bouguer density variations due to changing surface conditions can be used routinely in the reduction of gravity data.'

Terrain Corrections for Airborne Gravity Gradient Measurements (Chinnery, 1961)

'A method is given for the calculation of terrain corrections for airborne measurements of the vertical gradient of gravity. This includes a short account of the theory concerned, a description of the practical procedure, a complete set of numerical tables, and some examples of their application. The method described is shown to be very flexible both with regard to aircraft height and to complexities of topography. Some discussion is also given of the magnitudes of topographic effects on the gravity gradient and it is shown that terrain corrections are in general more important here than in normal gravity work.'

An Integrating Technique for Airborne Gravity Gradient Measurements (Paterson, 1961).

'For some purposes it may be desirable to work with the gravity force g rather than its vertical gradient g'. A simple method has been tested by which measurements of g' on a plane surface can be integrated to produce values of g anywhere in space above the plane of measurement. The method appears to show promising results.'

Evaluation of the Dominion Observatory Bronze Pendulum Apparatus (Hamilton, 1961).

'From an analysis of all the observations on the pendulum pier in Ottawa over a three-year period it is shown that there is a gradual increase of some 4×10^{-7}s followed by a decrease of about the same amount which is believed to be due partly to a change in operating temperature and partly to creep in the bronze metal. From analysis of variance it is shown that the standard deviation for a gravity difference may be as low as 0.15 or as high as 0.58 mgal depending on the method of computation; this shows that the internal consistency is much better than the consistency between sets of observations.

The temperature control system is discussed and the record of thermistor resistances for one pendulum pair is presented to show that there is negligible correlation between temperature and residual errors and only partial correlation with the long term drift of the pendulum periods. Other possible sources of error are discussed and it is concluded that shocks of undetermined origin affect the pendulums each time they are removed from the thermostatted case.'

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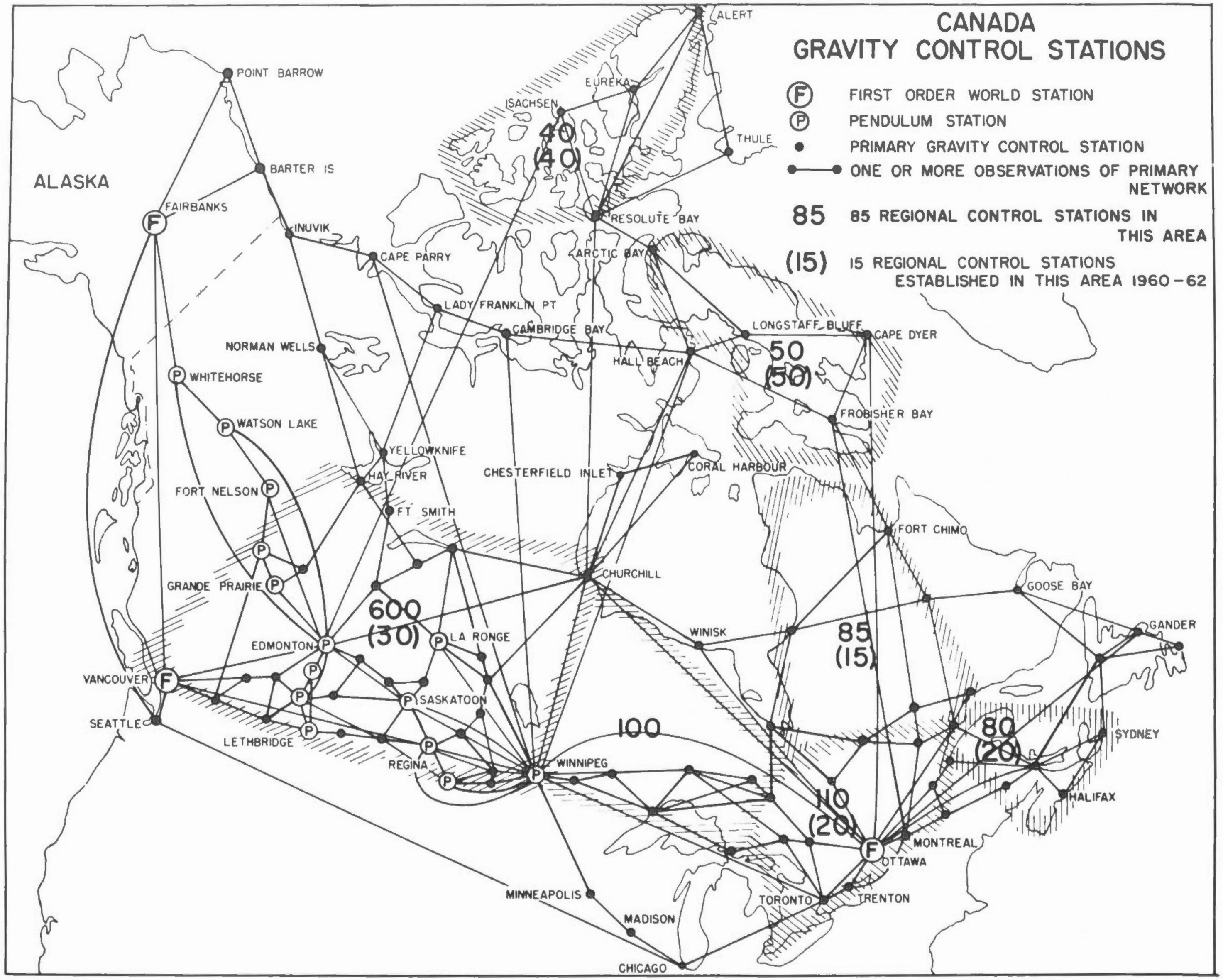
CANADA
GRAVITY CONTROL STATIONS
FIRST ORDER WORLD STATION
PENDULUM STATION
PRIMARY GRAVITY CONTROL STATION
ONE OR MORE OBSERVATIONS OF PRIMARY NETWORK
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(15) 15 REGIONAL CONTROL STATIONS ESTABLISHED IN THIS AREA 1960-62
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FAIRBANKS
INUVIK
CAPE PARRY
ALERT
EUREKA
ISACHSEN
THULE
RESOLUTE BAY
ARCTIC BAY
LADY FRANKLIN PT
CAMBRIDGE BAY
LONGSTAFF BLUFF
CAPE DYER
HALL BEACH
FROBISHER BAY
NORMAN WELLS
WHITEHORSE
WATSON LAKE
YELLOWKNIFE
HAY RIVER
FT SMITH
FORT NELSON
CHESTERFIELD INLET
CORAL HARBOUR
FORT CHIMO
CHURCHILL
GOOSE BAY
GANDER
GRANDE PRAIRIE
EDMONTON
LA RONGE
WINISK
VANCOUVER
SEATTLE
LETHBRIDGE
SASKATOON
REGINA
WINNIPEG
SYDNEY
HALIFAX
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OTTAWA
TORONTO
TRENTON
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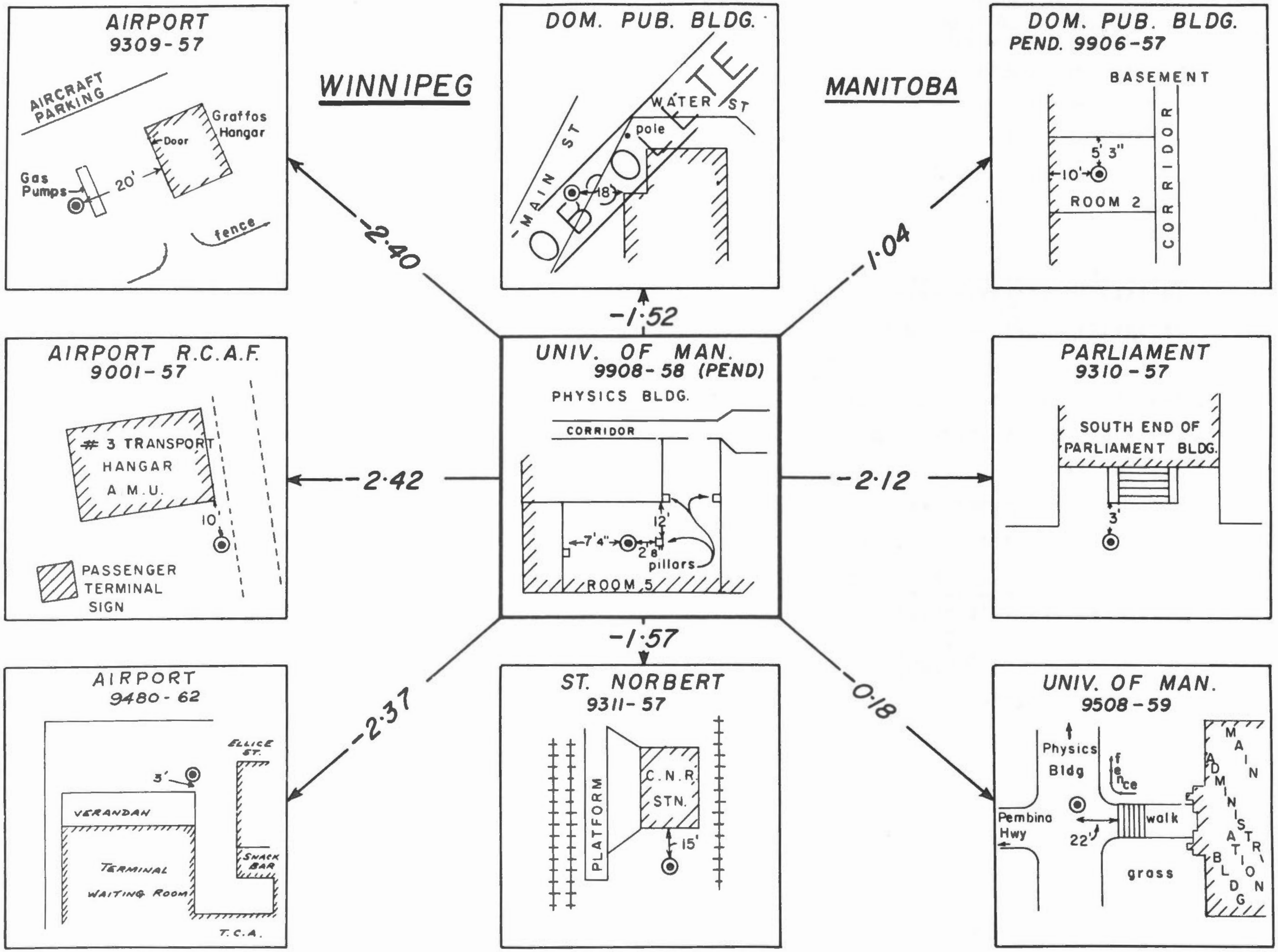
Figure 1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AIRCRAFT PARKING
Graffos Hangar
Door
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-2·40
DOM. PUB. BLDG.
OBSOLETE
WATER ST
MAIN ST
pole
18
-1·52
DOM. PUB. BLDG.
PEND. 9906-57
BASEMENT
CORRIDOR
5' 3"
10'
ROOM 2
-1·04
AIRPORT R.C.A.F.
9001-57
3 TRANSPORT HANGAR A.M.U.
10'
PASSENGER TERMINAL SIGN
-2·42
UNIV. OF MAN.
9908-58 (PEND)
PHYSICS BLDG.
CORRIDOR
12'
7' 4"
2' 8"
pillars
ROOM 5
PARLIAMENT
9310-57
SOUTH END OF PARLIAMENT BLDG.
3'
-2·12
AIRPORT
9480-62
ELLICE ST.
3'
VERANDAH
TERMINAL WAITING ROOM
SNACK BAR
T.C.A.
-2·37
ST. NORBERT
9311-57
PLATFORM
C.N.R. STN.
15'
-1·57
UNIV. OF MAN.
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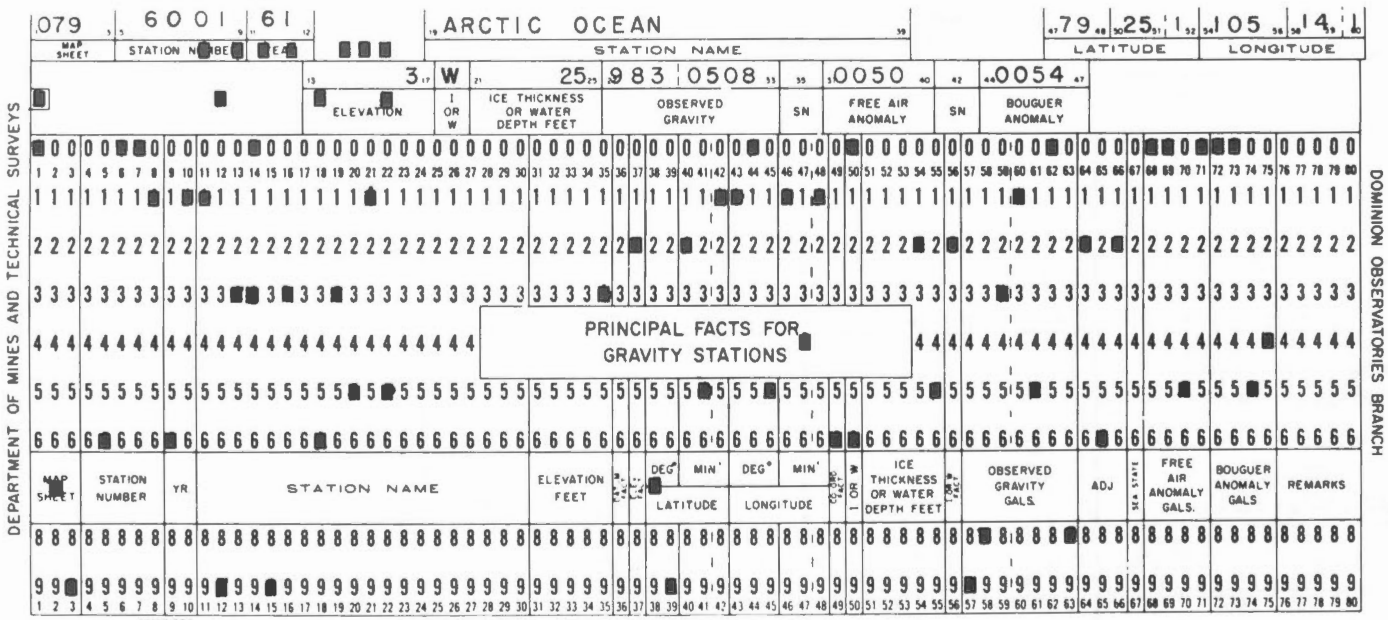
Figure 2



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OBSERVED GRAVITY
SN
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PRINCIPAL FACTS FOR GRAVITY STATIONS
DEPARTMENT OF MINES AND TECHNICAL SURVEYS
DOMINION OBSERVATORIES BRANCH
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STATION NUMBER
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LATITUDE
LONGITUDE
ICE THICKNESS OR WATER DEPTH FEET
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SEA STATE
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BOUGUER ANOMALY GALS
REMARKS
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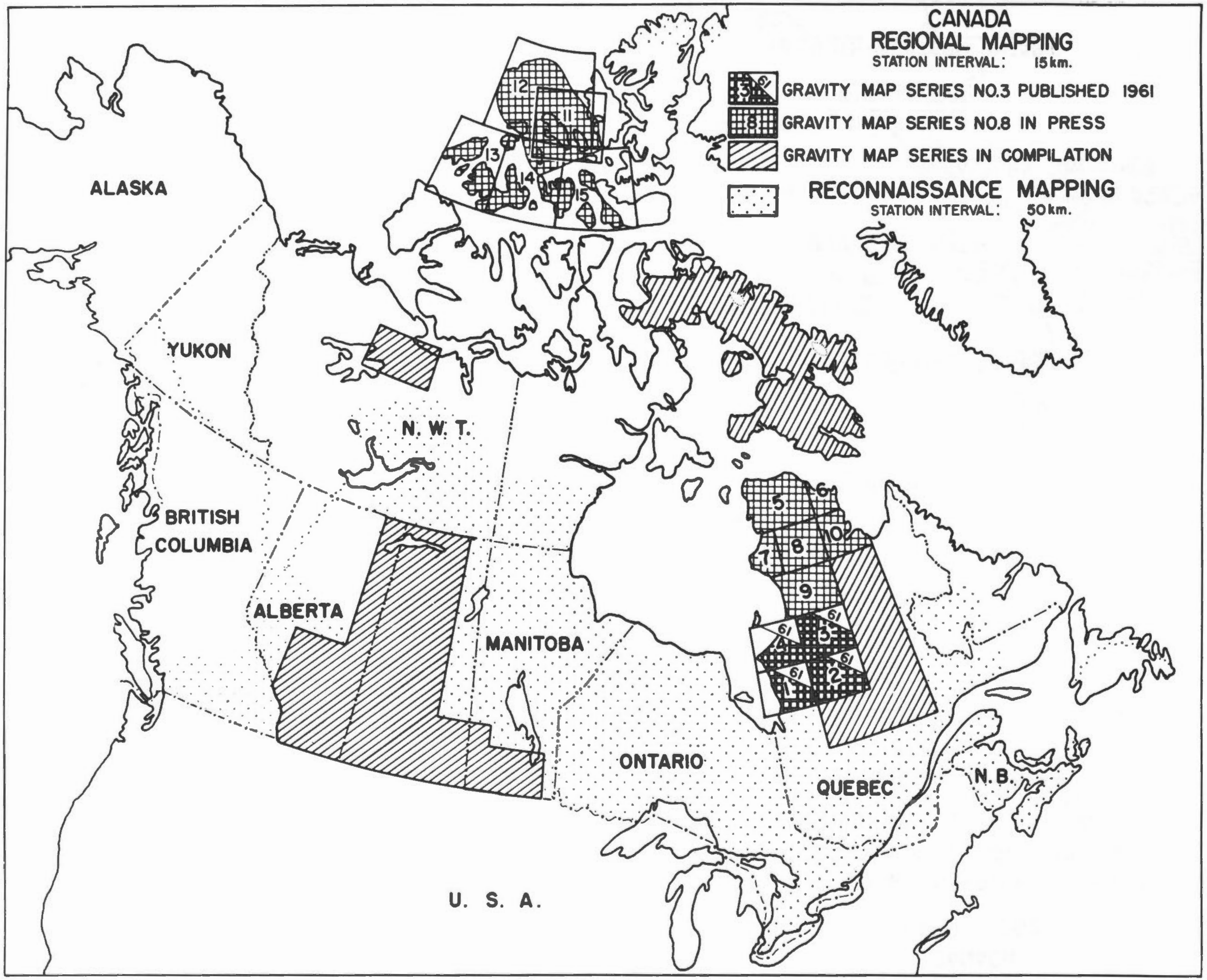
Figure 3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GRAVITY MAP SERIES IN COMPILATION
RECONNAISSANCE MAPPING
STATION INTERVAL: 50km.
ALASKA
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BRITISH COLUMBIA
ALBERTA
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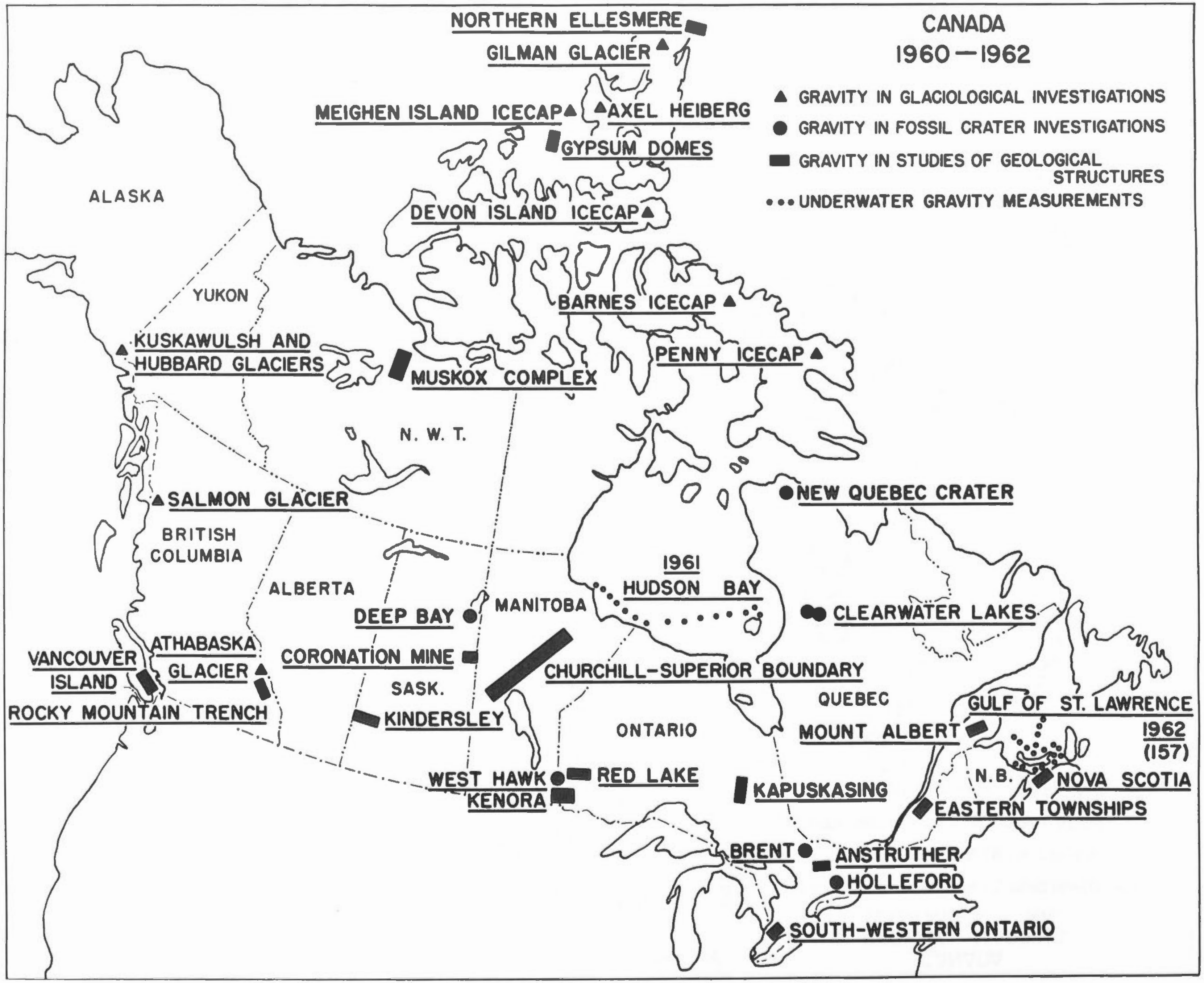
QUEBEC
N. B.
U. S. A.

Figure 4


CANADA
1960—1962
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● GRAVITY IN FOSSIL CRATER INVESTIGATIONS
▬ GRAVITY IN STUDIES OF GEOLOGICAL STRUCTURES
••• UNDERWATER GRAVITY MEASUREMENTS
NORTHERN ELLESMERE
GILMAN GLACIER
MEIGHEN ISLAND ICECAP
AXEL HEIBERG
GYPSUM DOMES
DEVON ISLAND ICECAP
ALASKA
YUKON
BARNES ICECAP
KUSKAWULSH AND HUBBARD GLACIERS
MUSKOX COMPLEX
PENNY ICECAP
N. W. T.
NEW QUEBEC CRATER
SALMON GLACIER
BRITISH COLUMBIA
1961
HUDSON BAY
ALBERTA
DEEP BAY
MANITOBA
CLEARWATER LAKES
VANCOUVER ISLAND
ATHABASKA GLACIER
CORONATION MINE
CHURCHILL-SUPERIOR BOUNDARY
SASK.
QUEBEC
GULF OF ST. LAWRENCE
ROCKY MOUNTAIN TRENCH
KINDERSLEY
ONTARIO
MOUNT ALBERT
1962
(157)
N.B.
NOVA SCOTIA
WEST HAWK
RED LAKE
KAPUSKASING
KENORA
EASTERN TOWNSHIPS
BRENT
ANSTRUTHER
HOLLEFORD
SOUTH-WESTERN ONTARIO

Figure 5