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gravity measurements in canada january 1, 1967 to december 31, 1970

J. G. TANNER and R. A. GIBB

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Introduction

This report has been compiled at the request of the International Union of Geodesy and Geophysics (IUGG) for presentation at the Fifteenth General Assembly on behalf of the Associate Committee of Geodesy and Geophysics (ACGG), the National Committee representing Canada in the international union. Annual reports published by the subcommittee on Gravity of the ACGG in the Canadian Geophysical Bulletin (C.M. Carmichael, Editor) form the basis for this compilation. The gravity subcommittee includes representatives from universities, from government institutions and from the mineral industry. The present membership is:

A.E. Beck	University of Western Ontario
D.E.T. Bidgood	Nova Scotia Research Foundation
W.C. Brisbin	University of Manitoba
E.R. Deutsch	Memorial University of Newfoundland
R.M. Ellis	University of British Columbia
R.A. Gibb	Earth Physics Branch, Secretary
R.T. Haworth	Atlantic Oceanographic Laboratory, Bedford Institute
E. Krakiwsky	University of New Brunswick
T.H. Pezarro	Voyager Petroleums Ltd.
J.G. Tanner	Earth Physics Branch, Chairman
H.D. Valliant	Earth Physics Branch

The largest contributor to this report is the Earth Physics Branch (formerly the Dominion Observatory) of the Department of Energy, Mines and Resources, the federal agency responsible for mapping the gravity field in Canada and its coastal waters. Allied responsibilities include maintenance of gravity standards for Canada, operation of a gravity data bank, instrumental development and the application of gravity to geologic and geodetic problems in Canada.

A major contribution comes from the Atlantic Oceanographic Laboratory, Bedford Institute of the Marine Sciences Branch, Department of Energy, Mines and Resources. This institute is involved with surface gravity measurements at sea.

Several provincial agencies and several Canadian Universities are increasingly active in a diversity of gravity investigations as reported here.

Earth Physics Branch

Gravity standards

National primary net. An extensive series of pendulum and gravimeter measurements were carried out on the national primary net between 1967 and 1970. This network (Figure 1) consists of 64 stations interconnected by 1,500 LaCoste and Romberg gravimeter ties and six pendulum intervals.

The first full scale field evaluation of the rebuilt Canadian bronze pendulum apparatus was carried out over the North American calibration line between Mexico City and Fairbanks in 1967. The results of these measurements (Valliant, 1969) when compared with earlier Gulf and Cambridge pendulum measurements and with gravity values derived from combined adjustments of all existing gravimeter and pendulum measurements on the NACL, showed that an accuracy better than ±0.2 mgal could be achieved with two sets of measurements in opposite directions on any interval. In 1969, pendulum measurements were carried out at Ottawa, Winnipeg, Vancouver, Edmonton, Yellowknife, Fairbanks and Resolute. Environmental problems at Resolute and logistic difficulties in the initial Fairbanks - Resolute and Resolute - Ottawa ties caused large discrepancies between the incoming and outgoing legs. Satisfactory results were obtained on the repeated Ottawa - Resolute measurements but transportation difficulties have prevented a remeasurement of the Resolute - Fairbanks interval. An analysis of these measurements (Valliant, 1970, in press) indicates that an accuracy better than 0.2 mgal has been achieved. Comparisons with absolute measurements at Fairbanks, Denver and Boston carried out by Air Force Cambridge Research Laboratories, Bedford, Mass., using Faller's apparatus show that the Canadian pendulums agree with the absolute measurements to about 1 part in 20,000.

In order to minimize errors due to excentre corrections at points in the primary network nearly all excentre networks were reobserved or strengthened with new measurements. A large proportion of the 270 excentre stations in the network were reobserved during 1968 to 1970 and each excentre network readjusted. The standard errors of the adjusted excentre stations are generally less than 0.02 mgals.

During the period under review about 700 long range measurements with LaCoste and Romberg gravimeters were added to the 800 older LaCoste and Romberg measurements, the Canadian pendulum measurements, and the absolute measurements at Fairbanks and Boston to form the basis for adjusting the Canada net. During the adjustment, a larger dispersion in the gravimeter measurements carried out before the installation of vibration insulators in 1966, led to the development of a weighting system based on the elapsed time between successive readings of the gravimeters. Pendulum and absolute measurements were weighted according to their respective estimated variances.

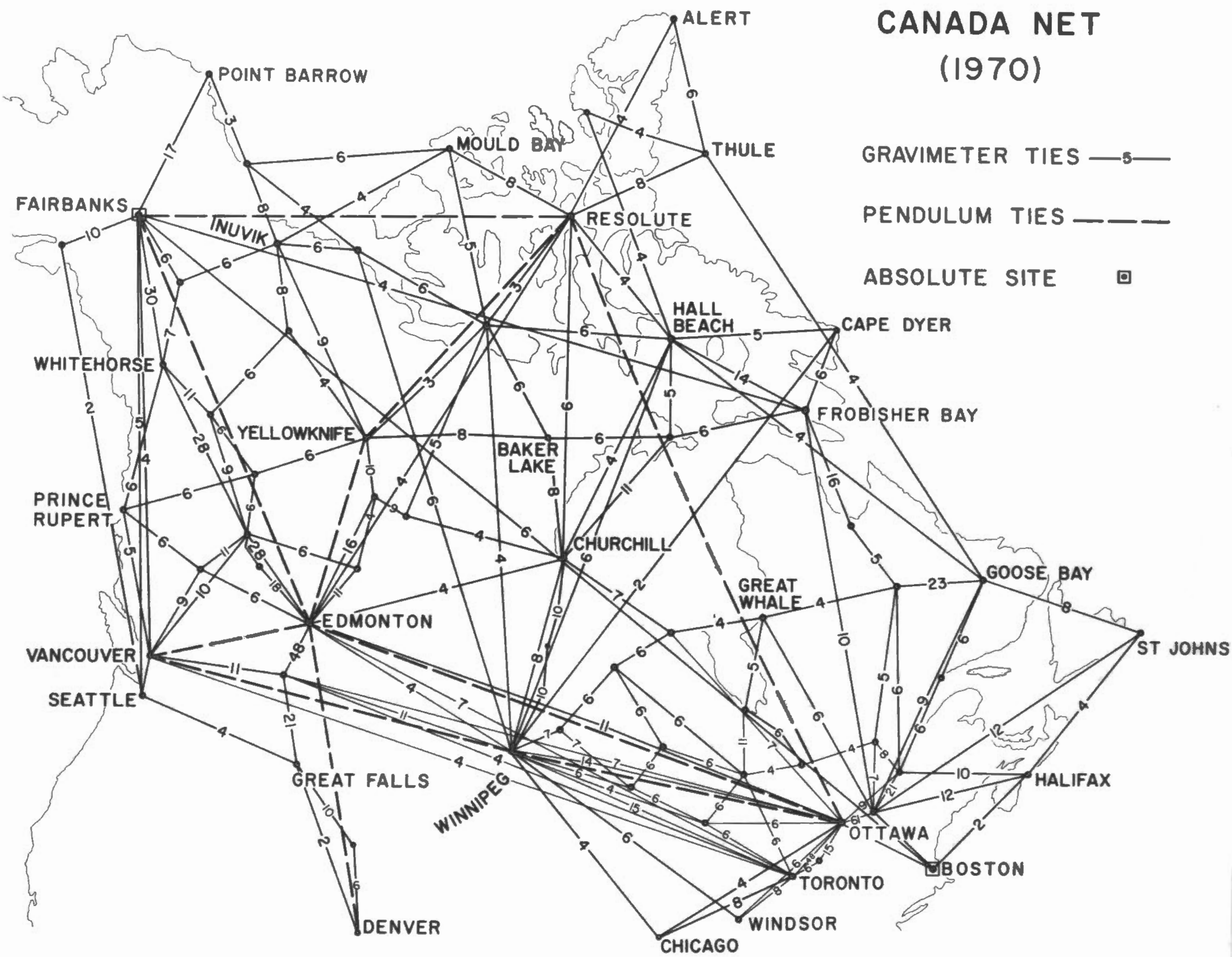

Figure 1. The Canadian primary net (1970).

The analysis of the primary network adjustment (R.K. McConnell, Earth Physics Branch, personal communication) indicates that gravity values in the primary net are accurate to ±0.05 mgals relative to the datum defined by the absolute measurements.

Adjustment of the secondary networks comprising some 17,000 ties between 3,000 control stations has been underway for some time. In order to reduce, adjust, and analyze this rapidly expanding file of data quickly and efficiently, considerable emphasis has been placed upon computer filing, retrieval and data reduction systems. These are described briefly in a subsequent paragraph.

World gravity net. The Earth Physics Branch has continued its participation in the work of Special Study Group 5 of the International Association of Geodesy. In 1967, C.T. Whalen of the 1381st Geodetic Survey Squadron, Cheyenne, Wyoming visited Ottawa to carry out preliminary adjustments of the world net using all available gravimeter and pendulum data. In 1968, R.K. McConnell of the Earth Physics Branch collaborated again with Mr. Whalen using the computing facilities of Aerospace Corporation in San Bernardino, California. In September of 1970 J.G. Tanner and R.K. McConnell presented the results of an adjustment of a world gravity net consisting of 270 stations to the Special Study Group 5 meeting held in Paris and participated in the development of plans for the final adjustment to be accomplished in 1971.

A few additional measurements on the world net were made by Earth Physics Branch personnel in 1969. Direct ties between absolute sites at Fairbanks, Boston and Bogota were carried out using three LaCoste and Romberg meters. Additional ties were made between South America and South Africa in co-operation with Professor Baglietto of the Institute of Geodesy, University of Buenos Aires.

Gravimeter tilt calibrator. A gravimeter tilt calibrator built at the Earth Physics Branch from plans supplied by Texas

Instruments Ltd., was used extensively by A.C. Hamilton to investigate dial non-linearaties in Worden type gravimeters. Discrepancies between calibrations of the same meter on the Earth Physics Branch tilt table and one at Texas Instruments led to an investigation of the table design. Precise angle measurement carried out by E. Greene of the National Research Council of Canada, Ottawa showed that the knife edge surface and the surface on which the Johannsen blocks rest were not sufficiently coplanar to eliminate erratic tilt angles due to slight horizontal movements of the table. As a result R.K. McConnell and J. Geuer designed a new tilt calibrator using a cast iron table tilted on precision steel balls. Automated lifting and tilting features were incorporated into the new design. Construction of the new table was completed late in 1970 and an extensive series of evaluation tests will be carried out in 1971. If the new design proves satisfactory, it will provide an efficient means of calibrating quartz type gravimeters before and after each field survey.

Gravity storage and retrieval system

In 1965, it became apparent that the existing punch card storage and retrieval system would soon be inadequate to handle the increasing number of new observations and the increasing requirement for plotting and other computer processing of the output file. Consequently, in that year, a study was made of the feasibility of a new storage and retrieval system using data files on magnetic tape and disk. This study included the preparation and documentation of the computer hardware requirements, system flow charts, program specifications, and program flow charts. Although some preliminary experimental programming was done, the project had to be postponed for two years because there was no access to a large computer suitable for use with such a system.

In 1967, with the installation of an IBM 360 Model 65 computer at the Computer Bureau in Ottawa and with the acquisition by the Division of a new X-Y data plotter which used magnetic tape as input, the development of the planned storage and retrieval system was begun. By the spring of 1969, the new system was operational. The present version of the system operates on an IBM 360 Model 85 computer at Systems Dimensions Limited in Ottawa. Its main components are a principal facts file of approximately 120,000 gravity observations stored on an IBM 2316 disk pack, and a suite of programs to store, update, and retrieve data from this file. Provision is made for output on the data plotter, the computer printer, punched cards, and magnetic tape.

Six major programs are used in this system. The **gravity traverse reduction program** is used to process the new observations, to detect errors in these observations, and to produce output records suitable for inclusion in the disk file. The **general program** produces maps at any scale on one of four different map projections showing the positions and values of selected gravity observations within a specified geographic area. Input in any combination from punched cards, card-image magnetic tape, and the disk file is possible. The plotting program can also select and display data within a specified range of any of the 14 data fields. Complete listings of the observations plotted on each map are provided automatically. The **general utility program** uses the disk file as input and produces punched cards, a card-image magnetic tape file, or a printer listing of selected observations within a specified geographical area. Given the latitude and longitude of the end points of a profile, the **profile plotting program** will select observations within a band of specified width along this line, interpolate them to the line, and plot a profile to the specified scale. The **file updating program** and the **file reorganization program** are used to update the disk file by the correction, deletion, or addition of data records. The former is used to process a small number of update records, while the latter is run whenever a large number of observations must be added to the file.

Using this system, the Division has been able to satisfy the needs of not only its own field officers and scientists but also those of universities, research institutions and the exploration industry. During the past year, the Division has processed approximately 100 requests for data from external agencies, involving the production of approximately 1,000 special maps and associated printer listings.

During the past year, work has progressed on the adjustment of the world gravity network and the Canadian gravity network and new values of gravity for the control stations in these networks will probably be adopted in the near future. In this same period, certain agencies in Canada such as the Bedford Institute and the Nova Scotia Research Foundation have offered their data for the file. Also, the subcommittee on gravity has recommended that this file will become a national repository for gravity data. These developments will require the recomputation of the input data during the coming year and some redesign of the system. The result of this redesign and recomputation will be a more complete and compact data record, a new file indexing system which will allow the addition of data from any part of the world, and a suite of more modular and more flexible programs. It is expected that this new system will be operational sometime in 1972.

Network processing and adjustment system

Concurrent with the development of the gravity storage and retrieval system, a compatible system for the processing, editing, and adjustment of observations taken at control stations in the Canadian gravity network has been developed. This system consists of four data files and eight major computer programs.

The **control station file**, which is the primary source for all control station information required by the system, consists of approximately 3,200 data records stored on a direct access file on an IBM 2316 disk pack, and a backup file on punched cards which provides the records necessary for the updating of this file. The **gravimeter file** consists of the conversion tables, calibration constants, and other parameters for approximately 50 instruments, and is stored as a direct access file on the same disk pack. The **network observation file** contains approximately 15,000 observations which have been taken at control stations in Canada and throughout the world, and is stored on punched cards. The **network tie file** is an intermediate file which is computed from the network observation file and is stored on magnetic tape with a backup file on punched cards.

The **control station file updating program** is used to modify the control station file by correction, deletion, or addition of data records. The **control station utility program** can select data records based on a number of different parameters and conditions, sort the output in various ways, and produce punched cards, a card-image tape file, or a printer listing of the selected and sorted control station records. All requests for control station descriptions are accompanied by a current printer listing from this program. The **tie processing program** uses the control station and gravimeter files to process the new network observations to produce network tie records on punched cards and a listing of these new ties. The **tie file updating program** uses punched card input to update the network tie file on magnetic tape by correction, deletion, and addition of these records. Using a file of control stations such as is produced by the control station utility program, the **network selection program** will select the gravimeters and network ties required for the adjustment of a particular network. This selected network can be plotted using the **network plotting program** to show the positions of the control stations, their names or identification numbers, and the gravity ties observed. The colour and type of line indicate the type of instrument used for a particular gravity tie. The gravity difference and the number of ties observed are also given. These network diagrams are very useful for editing a network and determining its structure. The **network editing program** is then used to edit and check the selected observations, set up the observation and fixing equations, apply various weighting functions, and produce an output file of the results. The **network adjustment program** uses this output file to form and solve the normal equations, list the adjusted observations, punch new control station cards, and perform statistical analysis on the results. The solution of the normal equations may be carried out either by matrix inversion for systems of less than 550 unknowns or by the Seidel iteration method for systems up to 3,500 unknowns.

Future development of this system will include the creation of a new network observation file on magnetic tape or disk, eliminating the intermediate network tie file, and the modification of the tie processing and network selection programs so that all computations and selections will be performed on a single file.

Regional gravity surveys

During the period under review emphasis continued to be given to the completion of the regional gravity mapping of Canada (gravity stations spaced at intervals of 10-15 km). Approximately 85 per cent of the regional measurements during the past four years were made by large helicopter supported field parties. Table I summarizes the observations by region and Figures 2 and 3 show the geographical coverage of the measurements.

Within the Canadian Shield and south of the Arctic Circle (latitude 66° 30′N) regional gravity observations are now complete. The first of the large systematic, helicopter supported regional mapping surveys was commenced in the southern Cordillera of British Columbia in 1968 using locations especially surveyed by the Surveys and Mapping Branch of the Department of Energy, Mines and Resources and by the Mapping and Charting Establishment, Department of National Defence. Gravity observations were made at elevations of up to 3,000 metres above sea level during this survey. In 1970 an Armed Forces survey party from the Mapping and Charting Establishment carried out gravity observations in conjunction with establishing horizontal and vertical control for topographical mapping.

During 1969 the Polar Continental Shelf Project moved from Mould Bay on Prince Patrick Island to its present site on the Mackenzie River Delta. The gravity coverage in the Beaufort Sea is shown in Figures 2 and 3.

Detailed surveys have been made over various geological features, of which the Morin Anorthosite is an example. Detailed studies of this type have shown the need for a more rapid and accurate means of obtaining vertical control. An elevation meter acquired in 1969 will provide a means of increasing both accuracy and density of elevation control in those areas with an adequate road network.

Regional gravity interpretation

Gulf of St. Lawrence. The underwater gravity survey of the Gulf of St. Lawrence was completed in 1967. Three important conclusions emerged from the study of these data (Goodacre, Brule and Cooper, 1969). The Bouguer anomaly field over the northern portion of the Gulf is similar to that of the adjacent Precambrian Shield, but a distinct change in anomaly level from negative in the north to more positive in the south occurs in the Gulf and is believed to mark the boundary between the Grenville and Appalachian geological provinces. Basic intrusive rocks characteristic of this boundary are out-

Table I. Regional Gravity Mapping by the Earth Physics Branch

Region	Area (sq. mi.)	No. of observations
1. Quebec and Newfoundland	210,000	3,041
2. Maritimes	80,000	1,833
3. Ontario	75,000	5,104
4. Prairie Provinces	35,000	3,572
5. Northwest Territories and Yukon	560,000	7,955
6. British Columbia	60,000	1,555
7. Polar Shelf	210,000	4,716
		27,776

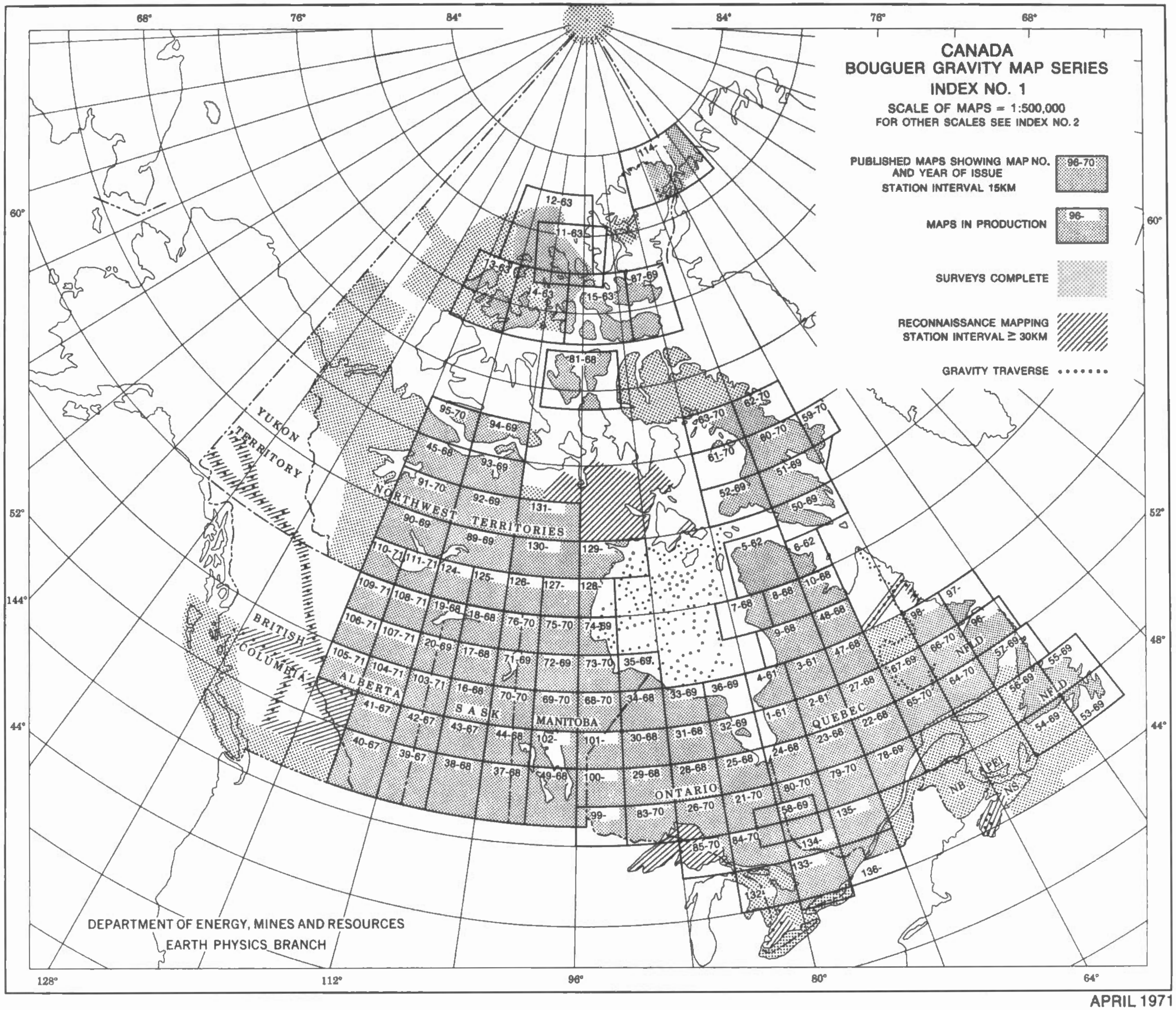

Figure 2. Distribution of gravity observations by the Earth Physics Branch to April, 1971.

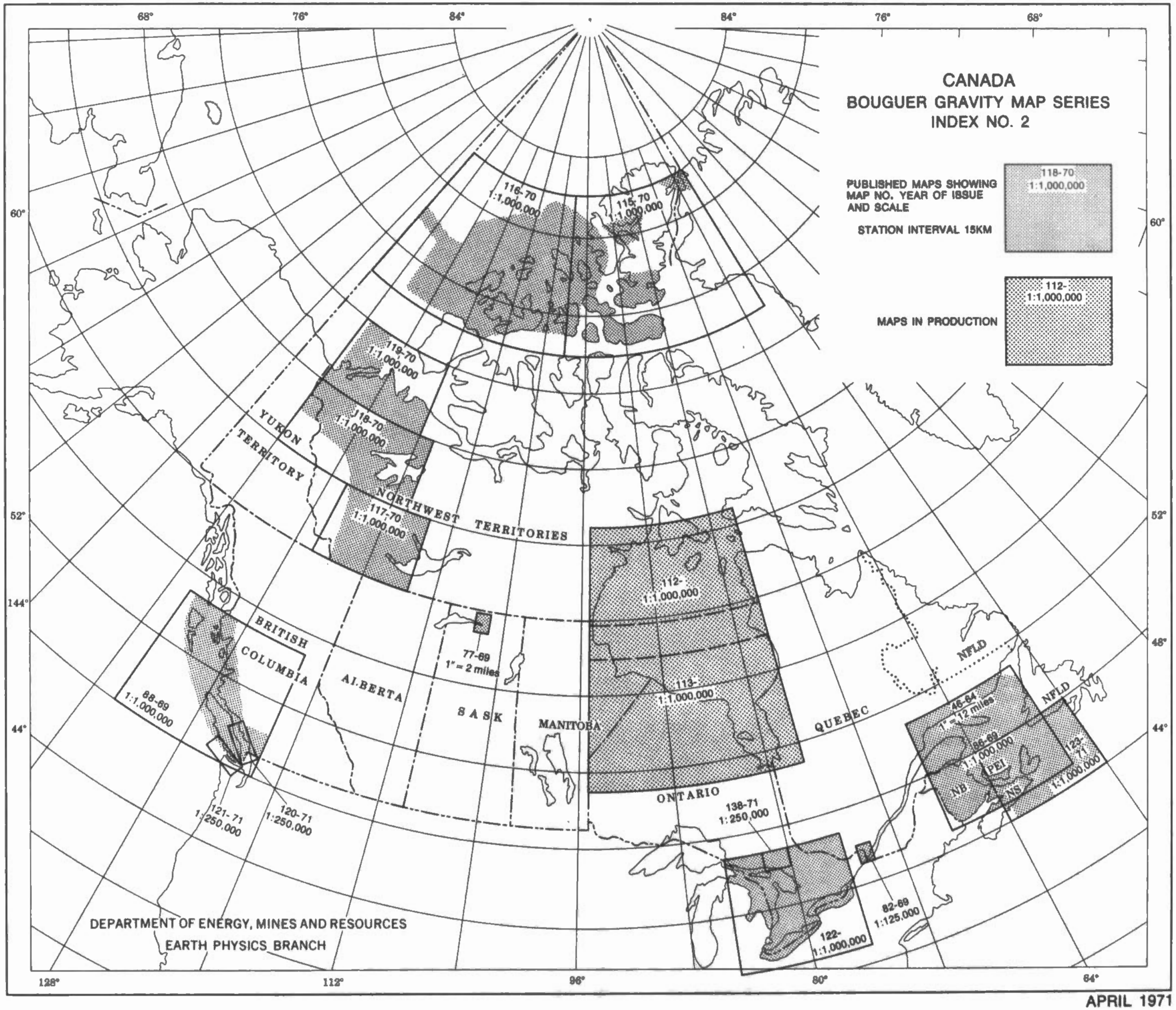

Figure 3. Additional maps published by the Earth Physics Branch to April, 1971.

lined by a series of gravity highs extending from Gaspe Peninsula to Port au Port Peninsula, Newfoundland. A gravity low of −60 mgal near the Magdalen Islands is attributed to Carboniferous sediments of low density or to Devonian granite or alternatively their combined effect.

Scotian Shelf. In 1970 the east coast underwater gravity survey was extended to cover Cabot Strait, the Laurentian Channel, and parts of St. Pierre Bank and Scotian Shelf (Stephens, Goodacre and Cooper, 1971). The gravity anomalies between southwestern Newfoundland and Cape Breton Island suggest a structural continuity between these regions. On the shelf the dominant feature of the gravity field is the Orpheus anomaly, a linear gravity low, first described by Loncarevic and Ewing (1967). Loncarevic and Ewing attribute the low to a trough filled with Carboniferous deposits including evaporites and younger sediments of low density. A broad gravity low south of the Orpheus anomaly resembles anomalies underlain by granite batholiths in Nova Scotia and may have a similar source. Positive anomalies on the Shelf are believed to be related to dense pre-Carboniferous metamorphic rocks (Stephens *et al.*, 1971).

Canadian Shield

Quebec. The major gravity anomalies of Quebec were described by Tanner (1969). Three major anomalies, the Cape Smith high, the Labrador Trough low and the Grenville Front low, are associated with the boundaries between the Superior Province and younger structural provinces of the Shield. The Cape Smith high is believed to be caused by a fold belt of dense Proterozoic volcanic, sedimentary and basic intrusive rocks. Flanking gravity lows probably result from local crustal thickening which compensates the crustal load of the fold belt. The negative anomalies associated with the Labrador Trough and the Grenville Front are interpreted as edge effects between continental blocks of differing density and thickness which are in relative isostatic equilibrium. In both cases the crust of the younger provinces are denser and thicker than the Superior nucleus.

Another set of major anomalies described by Tanner occurs over the anorthosite masses of the eastern Grenville Province. Interpretation of these anomalies suggests that the anorthosites extend to considerable depth in the crust. Tanner and McConnell (1970) noted a correlation between gravity highs and occurrences of granulites in northern Quebec. They suggest the possibility of a 'granulite layer' throughout the Superior Province of northern Quebec.

Northern Ontario. Innes, Goodacre, Weber and McConnell (1967) presented evidence which strengthens the hypothesis previously proposed by Innes that the Kapuskasing gravity high marks an ancient zone of crustal rifting. The Kapuskasing anomaly, a major feature of the gravity field of northern Ontario, cuts across the characteristic east-west trends of the Superior Province. Several carbonatite complexes, some as old as 1.7 m.y., are aligned along the Kapuskasing structure and may place an upper limit on the age of the rift.

Studies of the geology and geophysical results in northern Ontario have also led to formulation of two new hypotheses concerning the early structural history of the Canadian Shield. These hypotheses assume that plate tectonics operated in Precambrian time. Gibb (1971) suggests that the Slave and Superior cratons were once contiguous forming a single Archean craton. Rupture and sea-floor spreading caused them to separate with formation of an early Proterozoic ocean. This hypothesis is based on the remarkable morphological fit of the Slave Province and eastern Hudson Bay obtained by rotating the Slave Province about a pole at 75° 45′N (±15′), 51°W (±1°). Gibb and Walcott (1971) further suggest that closure of this ocean was responsible for formation of the now intervening Churchill Province mainly by accretion and coalescence of crustal fragments during the Hudsonian period of orogeny. Remnants of ancient oceanic deposits and oceanic crust juxtaposed with ancient continental margin deposits may still be preserved in suture zones within the Churchill Province. The most readily recognized probable suture is the circum-Superior belt which includes the Setting-Moak Lakes structure, the Fox River structure, and Cape Smith Belt, and Labrador Trough.

Northern Manitoba. Gibb (1968a and b) completed a study of the gravity anomalies adjacent to the Churchill-Superior boundary in northern Manitoba. Density determinations of some 2,000 Precambrian rock samples provided a basis for interpretation of the Bouguer anomalies in terms of relatively near-surface mass distributions in the upper crust. In some parts of the area there is excellent correlation between the surface rocks, their densities, and the Bouguer anomalies. The Nelson River gravity high outlines a belt of dense granulites. To the northwest three gravity lows are interpreted as the gravity effects of three granitic intrusions of which one is largely exposed at Split Lake and the others are largely buried although their presence is supported by the occurrence of numerous stocks of intrusive granite within the gravity lows. The Nelson River high is separated from these lows by a steep gravity gradient which marks a boundary between rocks of predominantly different ages (Hudsonian and Kenoran) between latitudes 54° and 56°N.

Northern Saskatchewan. A study of the gravity anomaly field of northern Saskatchewan and part of northeastern Alberta was completed by Walcott (1968). The principal feature of the Bouguer anomaly field is a belt of intense anomalies parallel to the northeast structural trend of the crystalline basement of the region, bounded on the northwest and southeast by regions of comparatively low gravity relief. This belt comprises the Fond du Lac low, a linear anomaly at least 500 km long, about 70 km broad and with an amplitude of about −30 mgal, and the smaller Lisgar Lake and Stony Rapids highs with amplitudes of about +20 mgal. The Fond du Lac low defines a belt of low density rocks which geological mapping of one area suggests are granites. If the change in load due to the crustal density changes is compensated, as implied by studies of earth deformation due to unloading of

Pleistocene lakes, then the crust is about 5 km thinner beneath the low than in adjacent areas. A three dimensional model based on postulates of complete compensation and lateral changes in crustal density can explain the major features of the anomaly field.

Northwest Territories. A gravity map of the Coppermine region, Northwest Territories has been published by Hornal (1968). A large gravity high is related to the Coppermine basalt flows, the Muskox ultrabasic intrusion and the diabase dyke swarms in the area. Secondary features include (i) gravity highs along the north shore of Great Bear Lake and south of the Muskox intrusion, and (ii) gravity lows attributed to granites, in the vicinity of the Dismal Lakes and Coronation Gulf. A detailed gravity survey over the Muskox intrusion showed a smoother gravity field than expected, probably because a considerable portion of the dense olivine layers of the intrusion have been altered to less dense serpentine.

Interior Plains. In northern Alberta the gravity field is dominated by the gradual decrease in Bouguer anomaly towards the Rocky Mountains; this decrease reflects the isostatic compensation for the increasing topographic load (Walcott and Boyd, 1970). Other major anomalies indicate changes in lithology within the upper part of the Precambrian basement. The MacDonald fault is well defined gravitationally in the area of its exposure as far southwestward as Pine Point. The Peace River Uplift of northern Alberta may be isostatic in origin. Walcott (1970b) has discussed this interpretation in terms of differential loading by sediments on originally compensated basement topography. If the wavelength of topography is large, differential vertical movements can occur causing amplification of the original topography and growth of an arch with sediments thicker and the load greater on either side of the arch.

Prior to interpreting the major gravity anomalies of the sedimentary basin in the southern Interior Plains, Dr. J. Maxant, a postdoctorate fellow, has undertaken an intensive study of the densities of the sedimentary rocks. Gamma-gamma logs from about 450 wells distributed throughout the basin are the main source of density information. Densities, formation tops and lithological descriptions, made available through the co-operation of numerous oil companies in Canada, are now stored on cards and preliminary analysis of these data has commenced.

Canadian Cordillera. A Bouguer anomaly map (scale 1:1,000,000) covering the continental shelf, Vancouver Island, the Queen Charlotte Islands and the fiords of the west coast of British Columbia has been published by Stacey, Stephens, Cooper and Brule (1969). More detailed gravity, magnetic and bathymetric maps are available for the Strait of Georgia and the Strait of Juan de Fuca (Stacey and Steele, 1970). The major features of the gravity field are: (1) a positive Bouguer anomaly along the western edge of the area, which is associated with the change from continental to oceanic crust, and (2) a negative anomaly along the Coast Mountains, which is attributed to the thickening of the continental crust below these mountains. On the eastern side of the Queen Charlotte Islands, Hecate Strait, Queen Charlotte Sound, and Vancouver Island, the average Bouguer anomaly is approximately zero, with local anomalies superimposed on a fairly flat gravity field. Several of these local anomalies are related to density variations in the surface rocks. A crustal model for the southern part of the Canadian Cordillera has been developed on the assumption that isostatic compensation is complete and local. The area included in the model lies between 49° and 51°N and extends from the Plains of southern Alberta to the vicinity of the Juan de Fuca Ridge. In the model, the thickness of the crust below the Plains, below the mountains of British Columbia and below the ocean west of Vancouver Island appears to be in good agreement with the depth of the M-discontinuity derived from seismic data. The results are ambiguous over Vancouver Island due to the very strong gravity anomaly related to the thinning of the crust west of the Island towards the ocean. However, the results suggest that the crust below the Island may be 70 km thick, which would be in reasonable agreement with seismic and magnetotelluric results, and with the requirements of plate tectonics (Berry, Jacoby, Niblett and Stacey, in press).

Hudson Bay. Weber and Goodacre (1968) have completed an analysis of the crust-mantle boundary in Hudson Bay from gravity and seismic observations. A study of the results of the gravity and seismic surveys in Hudson Bay in 1965 showed that the gravitational effect of a two-layer crustal model based on the seismically determined depths has no correlation with the observed gravity anomalies (Innes *et al.*, 1968). On the profile from Churchill to Povungnituk the gravity and seismic observations could be reconciled by postulating lateral variations of the acoustic compressional wave velocity within the crust. A crustal model was calculated, consistent with the seismic and gravity observations for which the crustal velocity varies from 6.15 to 6.56 km/sec and the postulated depths were almost entirely within the confidence limits of the original model.

The postulated velocity variations were compared with the lower refractor velocities of the shallow seismic survey on the hypotheses that the crustal velocities are systematically higher than the crystalline surface velocities and that there is a correlation between variations in crustal and surface velocities. The test was inconclusive because bottom refractor velocities were higher than crustal velocities in two areas where volcanic flows and high-velocity sediments might be present.

The case of linearly related velocity (V) and density (ρ) variations was analyzed and it was shown that the gravitational effect of the crust-mantle boundary undulations might be completely masked or even over-balanced by density changes in the crust if $\frac{d\rho}{dV} \geq 0.11\,\mathrm{g\,cm^{-4}\,sec}$. The crust could be characterized by having dominant velocity variations (in which case the gravity anomaly reflects the undulations of the crust-mantle boundary) or dominant density variations (in which case the gravity anomaly inversely reflects the crust-mantle boundary undulations) depending on the relationship between average crustal density and average crustal velocity.

Arctic Canada. Two Bouguer anomaly maps at a scale of 1:1,000,000 covering the area bounded by latitudes 74°N and 82°N and longitudes 60°W and 141°W have been compiled from about 8,800 gravity observations made in the period 1960-68 (Sobczak and Weber, 1970). On land, relationships between gravity anomalies and sedimentary facies changes and thickness of sediments have been established. Models of crustal structure have been derived from gravity, density, magnetic and seismic measurements. The regional free air anomaly map shows a series of positive elliptically-shaped anomalies aligned along the Polar Continental Margin. These anomalies, with amplitudes in excess of 100 mgal and with horizontal gradients of up to 2.5 mgal/km, are explained by the combined effect of sedimentary thickening (to 10 km) and crustal thinning (to 20 km) at the margin (Sobczak and Weber, in press).

A paper on the densities of crystalline, carbonate and clastic rocks from the Queen Elizabeth Islands has also been published (Sobczak, Weber and Roots, 1970).

A study of the gravity field over Somerset, Prince of Wales, and northern Baffin Islands has been presented by Berkhout (1970). Major negative anomlies occur on Borden and Brodeur peninsulas, in the area east of Agu Bay, on northeastern Somerset Island, and on northwestern Prince of Wales Island. These lows are explained by the presence of Upper Proterozoic metasedimentary rocks. An important conclusion is that during Upper Proterozoic time vast basins existed which were the sites of accumulation of clastic sediments. The observed gravity field outlines these basins and suggests that they may be interconnected.

A northerly trending gravity high is associated with the Boothia Uplift and two parallel highs occur to the west of it, all three being separated by gravity lows. The density contrast between crystalline rocks of the uplift and the adjacent Paleozoic rocks is not sufficient to explain the change of gravity over the Boothia Uplift. It is suggested that three northerly trending basement uplifts exist, separated by graben in which Upper Proterozoic quartzitic rocks occur. The Boothia Uplift became active again in Paleozoic time and overthrusts the quartzitic rocks in the west; this is reflected by observed negative anomalies along its western flank.

The gravity high over Prince Regent Inlet may reflect a basemant fault block beneath the Paleozoic rocks, whereas adjacent gravity lows represent the depressed areas occupied by thick deposits of Upper Proterozoic quartzitic rocks. The northerly and northeasterly trends of the two systems of basement fault blocks cut across the generally easterly (Archean) trend of basement structures, as on Baffin Island. Similar observations have been made in the Canadian Shield. Berkhout concludes that these unusual trends may possibly originate along ancient orogenic zones with northerly and northeasterly trends.

Three Bouguer anomaly maps at a scale of 1:1,000,000 and contoured at 5 mgal intervals have been prepared from 6,100 gravity observations made in the northern Interior Plains and on the Beaufort Sea from latitude 60°N to 72°N (Hornal, Sobczak, Burke and Stephens, 1970). The major features of the gravity field are: a gravity low over the Mackenzie Mountains which is attributed to a thickened sedimentary sequence and a deeper crust-mantle boundary; a relatively positive anomaly of 50 mgal striking north from Trout Lake to Great Bear Lake which reflects a ridge of mafic rock within the Precambrian basement; a negative anomaly over the Mackenzie River Delta of 55 mgal which results from the deposition of more than 21,000 feet of Cretaceous and Tertiary sediments; and a circular positive anomaly of 130 mgal situated south of Darnley Bay which is explained by a cone-shaped basic intrusion. Smaller variations in the gravity field in the Interior Plains may be attributed to changes in the depth to the Precambrian basement and density variations within the sedimentary column.

Detailed gravity investigations

Alexandria area, Ontario. Sobczak (1969) has completed a study of the gravity field in the Alexandria area of eastern Ontario. Negative Bouguer anomalies are correlated with the Chatham-Grenville syenite stock and a similar intrusion at Mount Rigaud on the southern border of the Grenville-A subprovince. It is postulated that the negative anomaly near Plaisance indicates the presence of a similar intrusion below the Paleozoic cover. The Alexandria high, a positive residual Bouguer anomaly which extends from Lunenburg to Pointe aux Chênes, may be explained by the presence of a basic lenticular body of thickness varying from 6,000 to 9,000 feet and width of 50,000 feet at a depth varying from 3,000 to 5,000 feet. The approximate thickness of the Grenville Series is 11,000 to 12,000 feet along the crest of the Alexandria high. The regional gravity gradient which increases from −30 milligals in the northwest to +10 milligals in the southeast of the area is correlated with a rise of over 3 kilometres (10,000 feet) of the Mohorovicic discontinuity.

Bancroft area, Ontario. W.R. Jacoby has completed a detailed gravity study of the Bancroft area, Ontario. The correlation between surface geology and gravity is excellent and there is enough density information to calculate the sub-surface mass distribution with considerable confidence. The low density granite gneiss, outcropping in large domes, batholiths and smaller plutons, seems to be extensive under a rather shallow metasedimentary cover 1-4 km thick. This indicates that the granite may represent partly pre-Grenville basement, remobilized or anatectically melted, and partly Grenville deposits, intensely metamorphosed and granitized. The granites and the gravity field show a distinct waveform over several wavelengths (20 to 30 km and 5 to 6 km). This wavelength is used to study the mechanics of granite emplacement. No vertical variation of the base of the granitic layer was indicated for the region.

Preparation of a comprehensive paper on this study was nearing completion at the end of 1970.

Timmins – Senneterre area, Ontario-Quebec. A study of the gravity field in the Timmins Senneterre mining belt was completed by Gibb, van Boeckel and Hornal (1969). The area is studded with many granite batholiths of variable composition which are outlined by intense negative gravity anomalies. The whole region was regarded as one great roof pendant and on this assumption model studies show that the volcanic belts extend to depths ranging from 3 to 5 km. Variations in anomaly level within the batholiths were correlated with compositional and density differences in the granites which have a compositional range which includes granodiorite and diorite. One of these batholiths, the Round Lake batholith, was the subject of a separate study (Gibb and van Boeckel, 1970). Two possible three-dimensional models of the batholith were presented which depend on different assumptions. The first model involves normal faulting of the batholith to explain the variations in anomaly level within the batholith. In this model the granite is assumed to be homogeneous in density and extends to a maximum depth of 10 km. Alternatively density variations corresponding to a facies change within the pluton may be the major cause of the local internal anomaly variations. In this interpretation the true thickness of the granite connot be evaluated as the whole region is assumed to be underlain by granite, but the maximum thickness of the surrounding basic volcanic rocks is 5 km.

Piercement structures in the Arctic Islands. Reconnaissance gravity surveys over three evaporite piercement domes in the Canadian Arctic Islands have been interpreted by Spector and Hornal (1970). Each dome was considered as a right-vertical cylinder divided into two homogeneous regions, a high density anhydrite zone (2.9 g/cm^3) overlying a low density gypsum and/or rock salt zone (2.3 g/cm^3). The cylinder is surrounded by a sedimentary sequence which has a uniform density of 2.4 g/cm^3. A least-squares approach was used to estimate the thickness of the anhydrite and gypsum-rock salt zones. The three sets of estimates gave a range of 200 to 550 m for the anhydrite thickness and a range of 700 to 5,500 m for the vertical extent of domes. In each case the depths were less than expected on the basis of estimates from seismic and geological data. Possible explanations for this are: (a) the cross-sectional area of each dome decreases with depth; (b) the existence of a transition zone where a gradation occurs between the high and low density zones; and (c) the effective density contrast of the low density zone is less than 0.1 g/cm^3.

Darnley Bay, Northwest Territories. The largest isolated gravity anomaly (130 mgal) discovered in Canada so far occurs at Darnley Bay, N.W.T. This anomaly was described by Hornal *et al.*, (1970) who suggested that it is caused by a basic intrusion with the shape of an inverted cone and a thickness of crustal dimensions (~40 km). Stacey (in press) has completed a further study of this anomaly and concludes that a cone-shaped basic intrusion with or without an ultrabasic core can explain the anomaly equally well. He compares his models with lopoliths having similar gravity anomalies, with Tertiary igneous centres in Scotland, and with present day sea-mounts.

Crater investigations. The investigation of Canadian structural and topographic features for evidence of origin by hyper-velocity impact of cosmic bodies began in 1950. By 1966 twelve Canadian sites had been shown to have the approximately circular outline, strong fracturing and brecciation and megascopic and microscopic evidence for shock metamorphism which are the main characteristics of eroded but otherwise undisturbed impact structures. Most of the sites had been investigated by gravity, magnetic and, in some cases, seismic methods. These studies showed the structures to have moderate to weak gravity anomalies consistent with their being underlain by rocks of low density, generally weak magnetic susceptibility and low seismic velocity to depths no greater than their radius at the surface.

Since 1966, a further six sites have been shown to contain shock metamorphosed rocks. Two of these, Steen River, Alberta and Lake St. Martin, Manitoba have weak surface expression, being buried by later sediments to a large extent. Two others, Mistastin Lake, Labrador, and Lake Wanapitei, Ontario closely resemble craters such as those at Clearwater Lake and Deep Bay. The remaining two, Charlevoix, Quebec and Sudbury, Ontario have been eroded and also deformed to some extent by tectonic events subsequent to their formation.

Geophysical data acquired to 1966 included gravity and magnetic surveys of eight craters and seismic surveys of five. Magnetic data mainly airborne are now available for an additional five sites and gravity for eight. A gravity Bouguer anomaly map has been published for Nicholson Lake crater (Dence *et al.*, 1968) while detailed maps by Dr. J. Popelar for Sudbury and Lake Wanapitei are in an advanced stage of preparation. Detailed gravity data are also available for Manicouagan and have been included in the regional gravity map series. Altogether of the eight, only Nicholson Lake and Lake Wanapitei have clearly expressed negative gravity anomaly fields. The rest all show indications of gravity lows, but lie within complex regional fields which appear to obscure or distort the crater anomalies. More detailed data are required to define clearly the anomalies associated with these structures.

Earth tides and crustal loading

Both the Earth Physics Branch and Dalhousie University have been concerned with this subject. Theoretical and experimental work has been directed mainly to the problem of correcting for the perturbing effect of the ocean tide on measurements of the earth tide. Until this correction can be made with high accuracy the original purpose of earth-tide measurements, the determination of the Love numbers, cannot be realized. A technique for estimating the correction has been developed by the Earth Physics Branch on the assumption of a given global distribution of ocean tides loading a Gutenberg-model earth. However, the Love numbers are presently better known than is the global distribution of ocean tides or the response of the lithosphere to surface loading. Consequently, this technique has been used only to explain the general features of the global variation in earth-tide measurements and, in a reverse sense, to identify definite regional anomalies due either to incorrect ocean tide data or to anomalous response of the lithosphere to surface loading. One such anomaly has been revealed by the disagreement between theoretical results obtained by the Earth Physics Branch with earth-tide measurements made at several locations across the United States by Columbia University. Measurements in the western half of the United States show a loading effect due to the tides in the eastern Pacific Ocean which is smaller than that expected on the basis of published ocean-tide data. The Earth Physics Branch intends during the next two years to make a series of earth-tide gravity measurements throughout Canada to identify and investigate other anomalies. These will be fairly short observations beginning in the north at Alert (lat. 83°N) and proceeding south along a mid-continental line to link with similar measurements in the United States.

On a regional scale the ocean tide is sometimes accurately known and the feasibility of using it to probe the upper layers of the earth has been investigated by Bower (1969) with measurements in England and by Lambert (1970) and Beaumont and Lambert with measurements in the Bay of Fundy area. This type of investigation, which relies principally on precise tilt measurements, will continue with a view to improving both the experimental and the analysis techniques available. At the Earth Physics Branch D. Bower is developing a long watertube tiltmeter which can be precisely calibrated and which is expected to be zero stable. Also at the Earth Physics Branch data analysis techniques such as the "response method" are being applied by A. Lambert in order to isolate the tidal component of tilt from coherent "noise" effects. C. Beaumont at Dalhousie University is constructing a finite-element crustal model of the Bay of Fundy area which will permit a generalized theoretical approach allowing for multilayers, lateral homogeneities and discontinuities.

The underground recording station near Ottawa was closed early in 1970 after approximately four years of recording both gravity and tilt earth-tide measurements. A new site in the same area is being prepared as a permanent station and will be equipped with both pendulum and hydrostatic type tiltmeters.

Flexural rigidity, thickness and viscosity of the lithosphere

In a series of recent studies Walcott (1970b) has modelled the earth's lithosphere and asthenosphere as a thin sheet and a fluid substratum respectively. The flexural rigidity of the lithosphere was deduced from observations of the wavelength and amplitude of bending in the vicinity of supercrustal loads. Data from Lake Bonneville given by M.D. Crittenden, Jr. were reinterpreted to give a value for the flexural rigidity of the lithosphere in the Basin and Range province of the western United States of 5×10^{22} Newton meters. Observations of loading in Canada give values for the flexural rigidity greater than 3×10^{23} N m for the Caribou Mountains in Northern Alberta (Walcott, 1970a); about 4×10^{23}N m for the topography over the Interior Plains (Walcott, 1970a); about 10^{23}N m for the Boothia uplift in arctic Canada (Walcott, 1970b); and about 10^{25}N m for the bending of the beaches of Pleistocene Lakes Agassiz and Algonquin. The flexure of the lithosphere at Hawaii and the bending of the oceanic lithosphere near island arcs give values of about 2×10^{23}N m (Walcott, 1970c). For short-term loads (10^3-10^4 years) the flexural rigidity of the continental lithosphere is almost two orders of magnitude larger than for long-term loads, indicating nonelastic behaviour of the lithosphere with a viscous (about 10^{23}N sec m^{-2}) as well as an elastic response to stress. From the values of the flexural rigidity the thickness of the continental lithosphere is inferred to be about 110 km and that of the oceanic lithosphere about 75 km or more. The anomalously low flexural rigidity of the lithosphere of the Basin and Range province may be due to a very thin lithosphere, only about 20 km thick, with hot, lower crustal material acting as an asthenosphere.

Gravity interpretation methods

Jacoby (1970) has published sets of diagrams of the normalized peak gravity effect of exposed rock bodies which can be used to determine the depth to which the bodies extend. The method is straightforward and is applicable to rock bodies of any shape.

An accurate method of computing the first vertical derivatives at different elevations from two-dimensional gravity profiles has been published by Paul (1970). He has shown that the accuracy of the computed first vertical derivative values depends significantly on a remainder term due to the finite length of the anomaly profile. Paul has also completed the development of a quantitative method to interpret gravity anomalies with circular symmetry. In this method the radial profile is first transformed to a vertical profile using the upward continuation principle, direct interpretation of the physical and geometrical parameters of the local causative body is then possible.

A weighted summation method for upward continuation of gravity data from a plane has been developed by Paul and Nagy (in press) under the assumption that the observations are available at regular intervals. The upward continued value has been expressed as the sum of individual gravity values and the corresponding theoretical coefficients. Besides the usual parameters involving horizontal and vertical distances, these theoretical coefficients have been generalized to be dependent also upon (i) the order of a low order polynomial assumed to represent the gravity variation around a grid point and (ii) the weights assigned to the gravity values at the nearest four points used for least square determination of the polynomial. The method has been tested with theoretical models and field gravity data and a paper has been submitted for publication.

Physical geodesy

Graphic representation. For the purpose of correlating various types of data (gravimetric, geodetic) and selecting areas to test various hypotheses, graphic representation of data is essential. The following developments are mentioned:

1. Compilation of an average free air gravity anomaly map of Canada. Using piecewise surface fitting technique, representative values over surface elements are obtained. The selection of a grid separation of about 55 km resulted in 2,923 surface elements on

which basis the free air map has been compiled. A paper describing the details is forthcoming.

2. Development of a special plotting package by which deflections of the vertical (input data represented as vector), geoidal height changes calculated from these reflection values can be plotted in the desired map projections and scales.

Computation of changes in the deflections of the vertical from gravity data. Programming of a method using local plane co-ordinate system and integrating out to a few hundred km around the computation point has been compiled. For checking the procedure see paragraph on model studies.

Model studies. The basic element for model studies is a right rectangular parallelopiped for which the gravity, the deflection of the vertical, the potential, and other quantities can be calculated with high precision. By combinations of elements, various potential fields can be computed to simulate practical situations satisfactorily. The model gravity field can then be used as a basis for upward continuation, computation of the deflections of the vertical, and other operations. Comparison of computations using the model field with those values obtained directly from the mass model serve not only to check the computations but also to provide a basis to specify requirements in the practical situation.

Upward continuation of gravity data from a plane. A method of upward continuation of potential fields has been developed assuming that the input data is regularly distributed over a plane. The computational procedure has been verified on a model for various elevations. A paper on this study by M. Paul and D. Nagy has been submitted for publication.

Upward continuation from an irregular surface. This is an extension of the above work and is being carried out by M. Paul. This method recognizes that the observations are made on actual topographic surface. The computational procedure is an iterative one which involves the integral for downward continuation from a plane.

Data representation. Y. Hagiwara, postdoctorate fellow, has investigated various methods of obtaining representative values from point distribution and techniques for predicting values in unsurveyed areas. Spherical harmonics expansion requires too many terms for adequate short wavelength representation to render its use feasible at present. The method accepted is that based on double Fourier series expansion.

Computation of geoid and the deflection of the vertical. Y. Hagiwara has also investigated techniques of using surface gravity data to provide the detail lacking in satellite measurements. The large wavelength structures for both the geoid and the deflection of the vertical have been computed from the spherical harmonics representation of the potential and gravity as determined by the Smithsonian Astrophysical Observatory 1967. More detailed computations of the geoid and the deflection values have been made using representative values from surface gravity data in surveyed regions and extrapolated values for unsurveyed regions within Canada. Co-ordinate transformation of the surface gravity data was also made for compatibility with satellite data. A publication giving the details of the various methods used and results obtained is under preparation.

Singularity. The singularities of the Stokes' and Vening-Meinesz's functions at the origin and their treatments are well known. In other cases when Fourier techniques or the methods of Molodenskii and Bjerhammer are used for the calculation of geoidal heights or the deflections of the vertical, the treatments of the singularities are more involved. M. Paul has examined this problem from the standpoint of practical computations.

Polar studies

In May 1967 and in April 1969 the Earth Physics Branch in co-operation with the Polar Continental Shelf Project carried out multidisciplinary geophysical studies in the vicinity of the North Pole. The expeditions under the leadership of J.R. Weber included participants from private industry and universities. The original objective was to establish a gravity traverse from Ellesmere Island to the North Pole. The biggest problem facing the project was precise navigation. Drift of the pack ice and atmospheric refraction results in accuracy of position fixes in the polar region obtained from conventional sun observations that is no better than a few kilometres. The problem was solved by R.L. Lillestrand from the Research Division of Control Data Corporation in Minneapolis who developed techniques involving sighting on various celestial targets during daytime and improved methods to solve for ice drift by computer. The computer was programmed to convert time of observations and zenith angles of the celestial target into position and drift velocity. A communication link for data transmission between the expedition and the computer in Minneapolis was established with the help of radio amateurs in Alert and Ottawa (Lillestrand, Grosch and Vanelli, 1967).

For logistical reasons it was not possible in 1967 to obtain aircraft suitable for making spot landings between Ellesmere Island and the Pole. Instead the expedition was airlifted to the Pole with a Bristol Freighter aircraft. The scientists drifted with the pack ice a distance of 30 km over a seven-day period during which time gravity observations were taken and the experimental navigational techniques were tested. These tests included ranging to an acoustic transponder dropped to the ocean floor.

Tilt measurements carried out on Fletcher's Ice Island (T-3) by Browne and Crary (1959)* more than a decade earlier, prompted an attempt to measure the tilt of the fluid surface of the ocean. Three holes were drilled through the ice and by levelling from water surface to water surface a tilt of eight seconds of arc was observed. It was realized that if such tilts persist over long distances along atmospheric pressure gradients (as Browne and Crary's observations indicated) it would imply sea level changes of a magnitude which would significantly affect the gravity measurements. Accordingly J.R. Weber developed a hydrostatic levelling

*Browne, I.M. and A.P. Crary. The movement of ice in the Arctic Ocean. In Arctic Sea Ice (ed. W.R. Thurston), N.R.C. Publ. 598, 191-209, *Nat. Acad. Sci.*, Washington, D.C.

system capable of measuring the tilt of the fluid ocean surface to an accuracy of about ±0.01 second of arc. Spot observations with this instrument in the vicinity of the North Pole in 1969 and in the Gulf of St. Lawrence in 1970 indicated tilts of up to about one second of arc (Weber and Lillestrand, 1971). Instrumentation is presently being developed with the aim of setting up an array of automatic tilt recording meters during the Arctic Ice Deformation Joint Experiment (AIDJEX) in the Arctic Ocean in 1973 in order to determine the deformation of the ocean surface with time.

During the 1969 expedition some 40 gravity stations were established between the Lincoln Sea and the North Pole, across the Lomonosov Ridge and in the vicinity of the North Pole using navigational techniques developed during the earlier expedition. The expedition established a base camp 50 km from the North Pole and over a period of 26 days drifted a distance of 80 km with the transpolar current. Advanced navigational techniques involving some 400 star observations, the use of satellite transit observations, and sonar trilateration from a number of acoustic transponders on the ocean floor were used to determine the path of the ice floe. An Omega VLF receiver was also used as a navigational aid, but because of unusually poor radio propagation conditions the system was inoperative most of the time. The relative agreement between the sonar drift path and the positions determined from the celestial observations is excellent, being of the order of 70 m. Evaluation of the satellite data has been delayed because the unique geometric configuration of satellite observations in the polar areas requires a different method for the reduction of the data than in more southerly latitudes. It is hoped to apply the results of the satellite data, the astronomic observations and the sonar trilateration to determine the absolute deflection of the plumbline. In addition to these geodetic observations continuous current measurements 2 m and 100 m below sea level and wind measurements 3 m above the ice surface as well as a number of hydro-casts were made.

Bedford Institute (Atlantic Oceanographic Laboratory)

Detailed gravity surveys

Hydrographic-geophysical survey of the eastern Canada Continental Shelf. Since 1966, the Atlantic Oceanographic Laboratory at the Bedford Institute has greatly increased its geophysical coverage of the eastern continental margin of Canada. This has been largely due to the collaboration existing between the Marine Geophysics Section and the Hydrographic Section of the Institute. The prime responsibility of the A.O.L. Hydrographic Section is charting all navigable waters within the Atlantic Region, as applicable to navigation requirements. The Region is defined as Canada's Atlantic Seaboard, the Gulf of St. Lawrence east of Pointe-des-Monts, Hudson Bay and the eastern Arctic. The surveys conducted by the Section satisfy requirements in navigation, fisheries and mineral exploration. All positioning of the ship is done by Lambda (low ambiguity decca) in the range/range mode, thus providing the most accurate navigation available in the areas surveyed so far. After a mutual study of each group's surveying techniques, it was decided that the two disciplines could be combined to produce a highly effective multi-disciplinary survey operation covering the Canadian east coast continental margin with measurements of bathymetry, gravity and magnetics.

The method of operation now existing is that the hydrographers carry out an initial survey of their proposed survey area at a line spacing of 2 or 4 miles, depending upon the density of measurements required to give good geophysical control. With the completion of this multidisciplinary portion of the survey, the hydrographers continue surveying the same area at a reduced line spacing, this being $^1/_2$ or 1 mile line spacing at water depths less than 50 fathoms. During this latter portion of the cruise geophysical studies are carried out as opportunity and manpower permits.

The data collection and reduction operation has now passed into the hands of the Hydrographic Section and a series of natural resources charts* are to be produced by them, with editions covering bathymetry, gravity (free air anomaly) and magnetics (total field). At present only the three editions of sheet 14956 are available (covering Marsden Squares 14956 and 14957: latitude 45° – 46°N, longitude 46° – 48°W). Four sheets covering the Tail of the Bank area (latitude 42° – 44°N, longitude 48° –52°W) are expected to be published before spring 1971. Geophysical data from the Grand Bank of Newfoundland and the Gulf of St. Lawrence is undergoing final processing at the Institute, and will be turned over to the cartographers at about the same time. The feasibility of extending natural resources charts to cover all Canadian offshore is presently being investigated by the Canadian Hydrographic Service.

While the routine data collection, reduction and chart production are in the hands of the Hydrographic Section, responsibilities for the initial planning of the geophysical aspects of the multidisciplinary cruises and their data interpretation still lie with the Marine Geophysics Section. This development is still in its infancy to the extent that the Hydrographic Section is still learning the techniques of geophysical surveying and data reduction. Meanwhile, Marine Geophysics is still attempting to exploit the positioning facilities provided by the surveys, in increasing the accuracy of sea surface gravity measurements as limited by the calculation of the Eotvos correction. The seismic group is also investigating the possibility of adding seismic reflection profiling to the functions of the survey.

Grand Banks. The area surveyed in 1966 and 1967 lies approximately between longitude 53°W and 44°W and latitude 45°N and 48°N. The most interesting features of the gravity charts reveal:

1. Steep horizontal gradients (up to 12 mgals per km).
2. A large "low" near the central portion of the survey area (minimum of −35 mgals with general low area extending over approximately 1° x 1°).

*Requests for these charts (price $1.00 each) may be made to: Hydrographic Chart Distribution Office, Canadian Hydrographic Service, 615 Booth Street, Ottawa, Canada.

3. An extensive "high" in the north central portion of the survey area (maximum of +136 mgals with general high area extending over approximately 1° x 1°).
4. A positive zone of +60 to +80 mgals associated with the Flemish Cap.
5. A belt of circular positive features with amplitudes from 20 to 100 mgals lying within and parallel to the 100 and 1,000 fathoms contour lines.

The top of the Grand Banks, especially within the 50 fathom contour is remarkably flat; therefore the steep gradients of the gravity field are due to major variations in the density distribution and/or structure of the subsurface rocks. This, coupled with the fact that the magnetic field in the same area is very smooth, indicates that the density variations are due to changes in structure within the sedimentary rock section. The gravity "lows" that are relatively small in areal extent are believed to be due to salt structures, while the large low in the central portion of the survey area is believed to be a basinal type feature with a total sedimentary rock thickness probably in excess of 6 km. In the area of survey, two 30-mile and one 150-mile refraction seismic lines were shot. Six distinct refraction layers were mapped with the following velocities: 1.67, 1.84, 2.69, 4.59, 5.40 and 6.03 km/sec. The highest velocity probably identifies cristalline basement rock in this area. As expected from previous investigations, a thickness of sedimentary rock in excess of 3 km was found in the vicinity of the long profile near 45°N and 49°W.

Gulf of St. Lawrence. In 1968 and 1969 a multidisciplinary survey was carried out in the Gulf of St. Lawrence. In surveying the Gulf east of 62°W and north of 47°N approximately 55,000 km of bathymetry, magnetics and gravity data were obtained. In the northeastern areas, surveyed in 1968, the gravity map covering part of the western flank of the Canadian Appalachians is featureless when compared with the gravity map of the Grand Banks which comprise part of the eastern flank. In the southeast Gulf, the gravity field is more complex and is dominated by a large negative free-air anomaly of −100 mgals (Bouguer anomaly of −60 mgals) to the northeast of Magdalen Islands. The analysis of this gravity information has only recently been started.

The surveyed area of the Gulf has been covered previously with sea-bottom gravity measurements made by the Gravity Division of Earth Physics Branch. The data in the eastern Gulf of St. Lawrence covering the areas of both the 1968 and 1969 A.O.L. surveys are being analyzed with the intention of determining whether this type of survey with greater concentration of survey lines (1- or 2-mile intervals), speed of data collection, and higher resolution of gravity anomalies is a better investment of money and manpower than the 8-mile grid bottom gravimeter survey providing more accurate gravity values. Initial comparison of the data yields a mean difference of 2.1 mgals between A.O.L. and E.P.B. over the 1969 survey area with the E.P.B. measurements being higher. Separating the E.P.B. measurements into different years of operation, there also appears to be a temporal variation in the underwater measurements. This is suspected to be the result of using different depth transducers in each of those years' operations. These and further results derived from the analysis will provide a basis for planning future complementary surveys by the two agencies.

Western Arctic. In response to the requirement for better navigation charts in the north the locale of the mapping program was shifted to the western Arctic for the 1970 field season. In the Beaufort Sea, bathymetry, gravity, and total magnetic field were measured at $^1/_4$ mile line spacing over 1,500 square miles. The area surveyed was centred on the Admiral's Finger, a shoal located approximately 50 miles north of Atkinson Point, and discovered in 1969 by *S.S. Manhattan* during her passage to Prudhoe Bay, Alaska.

During the course of the survey, about 80 additional shoals were discovered, some rising to within 17 metres of the surface. Observed gravity in the area was dominated by the shelf anomaly, exceeding 80 mgal at its maximum value, and paralleling the 100-metre contour. Except for the northeast corner of the survey area, there was no indication of shallow disturbances to the earth's magnetic field.

In conjunction with the western Arctic program, ships' passages from Victoria to the Beaufort Sea and then to Halifax provided additional opportunities for the collection of geophysical data, especially in Baffin Bay. Eight thousand km of gravity data were obtained by *CSS Hudson* and *CSS Baffin* between Resolute and Funk Island, Newfoundland. About one half of the data were collected during a survey of Baffin Bay in an attempt to ascertain its crustal structure.

Future plans. The proposed hydrographic-geophysical survey for 1971 will complete the surveying of Flemish Cap and then proceed northward along the continental shelves of Newfoundland and Labrador. At the present rate of coverage, and if priorities do not change, it is hoped to complete the survey up to Cape Chidley within the next five years.

Regional geophysical surveys

Mid - Atlantic Ridge. In 1968, the third Institute expedition to the Mid-Atlantic Ridge continued the comprehensive geophysical survey of the area between 45° and 46° which began with the voyage of *R.R.S. Discovery II* in 1960. Two ships were used in this survey to provide a shooting and receiving ship for a seismic experiment carried out on the eastern flanks of the ridge. Satellite navigation provided absolute positioning for the survey and radar transponder buoys were moored to provide accurate navigation within the survey area. Nine thousand km of bathymetric, magnetic and gravity measurements were made at a spacing of less than two miles to complete the detailed survey of the western flank of the ridge. In addition some 4,000 km of surveying were completed on the eastern flank. The total coverage is now approximately between 45°N and 46°N from 26°30'W to 30°W. All the gravity data obtained during the three expeditions have now been compiled and the data adjusted. Free air and Bouguer anomalies have been calculated for the entire region and interpretation is proceeding. The associated seismic refraction data will be used in model studies to be made on the crustal structure of the 3° by 1° area. Preliminary gravity results from the combined surveys were included in a paper presented at the 50th Annual General Meeting of the American Geophysical Union (A.G.U.).

Bay of Fundy. Three thousand seven hundred kilometres of gravity, magnetic and bathymetric data acquired in the Bay of Fundy (between 66°W and 67°10′W from 44°10′N to 45°10′N) have been processed and reduced to free air and Bouguer gravity anomalies and total magnetic field. An interpretation of the data has been made and a paper is being prepared for publication.

Hudson Strait. Gravity data on two tracks to and from Hudson Bay have been reduced and are being used in an interpretation of the structure of Ungava Bay and Hudson Strait based on all geophysical observations in this area. This work has been published by Grant and Manchester (1970).

North American Basin. A series of N-S traverses on which geophysical data are collected is in progress in the western North Atlantic. For this program, *CSS Baffin* and *CSS Hudson* were used on an opportunity basis as they travelled to and from the Caribbean on hydrographic training and geological research cruises. Magnetic and gravity coverage now extends between 45°N and 20°N along meridians at 2 $^1/_2$° intervals between 55°W and 70°W. Gravity data have also been collected along meridians 55°W, 57 $^1/_2$°W, 64°W and 70°W. A graduate student at Queen's University is examining the combined data.

Hudson '70. As a Canadian contribution to the Oceanographic Decade, *CSS Hudson* undertook a one-year oceanographic expedition named Hudson '70 comprising a circumnavigation of North and South America. An extensive marine geophysical program has been carried out as part of the expedition. Upon the departure of *CSS Hudson* for the Arctic from Victoria, British Columbia, 35,000 km of bathymetry, gravity and magnetic field data had been collected. This had been supplemented with 1,670 km of continuous seismic profiling, a major seismic refraction experiment, 13 heat flow measurements, 14 dredge hauls and the collection of two cores during detailed surveys in selected areas.

In the Atlantic, the track of *CSS Hudson* from Halifax to Rio de Janeiro provided gravity, magnetic and bathymetry data to add to that collected by *CSS Hudson* and *CSS Baffin* on long traverses from Nova Scotia to Europe, the Caribbean and the Arctic. These regional data will assist in our investigation of the northwest Atlantic-North America plate.

In the Pacific the geophysical investigation, while providing similar regional data to that obtained in the Atlantic, included the survey of an area adjacent to the contact between the Juan de Fuca, North America and Pacific plates. Seven thousand kilometres of gravity and magnetic data and 9,500 km of bathymetry data extended the previously surveyed section of the Juan de Fuca Ridge (the western boundary of the Juan de Fuca plate) towards the Queen Charlotte Island fault. Detailed station work was also carried out in the Explorer Trench which may be the last expression of the East Pacific Rise before its termination at the Queen Charlotte Island fault.

Regional studies of the Gulf of Alaska are also planned as a result of bathymetry, gravity and magnetic field data collected on five adjacent tracks of *CSS Hudson, CSS Baffin* and *CSS Parizeau* in the area while en route to and from the Arctic.

In the southeast Pacific, a geophysical profile was made over a feature which may be associated with the southern portion of the East Pacific Rise. A deep trench and adjacent peak (with a vertical separation of 3 km) were found in an area previously thought to exhibit few tectonic features. It appears that the feature may be part of a long fracture of the East Pacific Rise and it is hoped to name it the Hudson Fracture Zone.

The gravity data collected along latitude 150°W from the Antarctic ice field to the Alaska Shelf are being used in a geodetic program in ultimate support of a proposed oceanographic satellite. Determination of the difference in height between the isobaric sea surface and the geoid gives the change in potential of an isobaric surface. From this can be calculated the potential of all other isobaric surfaces, wherein lies the key to ocean current transport. Orbital perturbation analysis of satellite track observations provides the low order harmonics of the geoid. At present the higher order harmonics may only be obtained at the sea surface. In order to determine the high harmonics of the geoid along the path of a polar orbiting satellite, a gravimetric determination of the geoid was made along 150°W between 63°S and 57°N on the assumption that variations in the gravity are independent of longitude. Future satellite altimeter profiling of the sea surface with reference to this geoidal section will enable an absolute dynamic section to be made.

En route home to Dartmouth, *CSS Hudson* and *CSS Baffin* carried out a geophysical program in Baffin Bay. Previous work in the Labrador Sea has indicated the presence of a ridge structure buried beneath the sea floor. This ridge may have been the focus for the ancient separation of Greenland from Canada. Whether this proposed ridge extends into Baffin Bay is not known. The few days spent by the two ships in Baffin Bay were intended to provide the answer to one fundamental question: is the crust of Baffin Bay oceanic or continental? The main evidence for concluding that the crust was oceanic came from a seismic refraction experiment conducted along the axis of the Bay. In support of this, seismic reflection profiling together with bathymetry, gravity and magnetic surveying was carried out. The results of this activity will be used for planning subsequent cruises to areas of Baffin Bay requiring detailed investigation.

Environmental tests

Satellite navigation cruise (CSS Baffin 022-69). Extensive trials and comparisons between the ITT and Magnavox satellite navigation receivers were carried out on this cruise. Because of the excellent navigation facilities available (incorporating positioning by automatically recorded D.R., satellite fixes, Decca, Hi-fix, Omega and VLF) it was hoped to isolate some of the errors involved in the measurement of gravity at sea. Our two Askania sea gravimeters were operated on the same Anschutz gyrostabilized platform, each gravimeter being connected to a separate cross-coupling analog computer. Unfortunately the weather was so good and the ship motion so limited that the errors encountered were very small.

Laboratory tests. The extension of the laboratory wing of Bedford Institute in 1969 has included the provision of two laboratories dedicated solely to gravity studies. One is used as a "quiet laboratory" with a floor level platform isolated from the building. Another platform, provided for seismic studies, is coupled directly to bedrock and is also isolated from the building. No vibration testing has yet been performed on either of these platforms to determine the extent of their isolation. When this has been done, consideration will be given to setting up a gravity reference station on each of these platforms.

While the two Askania sea gravimeters have been land based, work has been carried out to determine some of the torsional parameters of the measuring system, and in particular linearity. This work was necessary on two counts. A proposal has been made to produce a completely digital processing system for the sea gravimeter. To do this, the digital filter employed must be tailored precisely to the linearity of the gravimeter measuring system. Secondly, the investigation of cross-coupling errors in gravity measurements at sea suggested that there might be an asymmetry in these errors and that this might be attributed to the non-linearity of the meter. The investigation demonstrated a non-linearity in the system which will have to be compensated for in the proposed digital processing system.

The cross-coupling computer originally built in 1965 has been modified, redesigned and completely rebuilt. It underwent extensive sea trials in its revised form early in 1969 and has been employed in correction of gravity data in the field ever since. With the continuous computation and logging of cross-coupling error data, on line correction for these errors is now feasible.

Memorial University of Newfoundland

Trans-Newfoundland gravity profile

An 800-km gravity profile, with 0.8 km station spacing, has been established along the Trans-Canada Highway between Port-aux-Basques and Come-by-Chance, Newfoundland. About one-third of the elevations were obtained from precise levelling, the remainder from an improved "one-base" barometric method which yielded a standard deviation less than half as large as that associated with the traditional "one-base" method. A total of 144 rock samples was collected along or near the profile to aid in the interpretation.

A qualitative profile interpretation has suggested the presence of unmapped gypsum deposits in southwestern Newfoundland, and intrusive bodies at several locations along the route. A detailed model study between Notre Dame Junction and Traytown shows the Ackley batholith to be a funnel shaped lopolith; it also shows this region to be underlain by an intermediate to basic layer, which may be a continuation of the layer inferred at 5-10 km depth from a gravity survey in eastern Notre Dame Bay (Miller, 1970).

Notre Dame Bay gravity investigation

A gravity survey covering 2,500 km^2 at 2.5 km spacing was conducted on islands and the coast of Notre Dame Bay near the eastern boundary of the Paleozoic Mobile Belt of Newfoundland. The Bouguer anomaly field shows good correlation with dominant features of the surface geology: (1) a strong northeasterly structural trend; (2) the Luke's Arm fault; (3) several extensive granitic bodies; however, no significant anomalies were observed over sedimentary areas. Preliminary qualitative interpretation of the published total-intensity aeromagnetic maps indicates some overall correlation with gravity and surface geology.

A satisfactory fit to the Bouguer field was obtained from three-dimensional model studies, dividing the area by geological criteria into 13 blocks, each with a mean density derived from rock samples. From the model results, two new features may be proposed:

1. A structural discontinuity near Change Islands, suggested also on the aeromagnetic maps, separating the eastern (Fogo-Change Islands) and western parts of the survey area.
2. A basic to ultrabasic layer at 5-10 km depth to explain the overall positive character of the Bouguer anomalies. This layer appears to be a landward continuation of the intermediate layer of Sheridan and Drake (1968).*

Nova Scotia Research Foundation

During the past four years some 15,000 gravity stations have been observed by the Nova Scotia Research Foundation in Nova Scotia and adjacent regions. A program of regional gravity surveying in Nova Scotia is underway. Particular emphasis is given to areas underlain by Lower Mississippian rocks which may contain diapiric salt structures. Many detailed surveys have been made to investigate possible deposits of barite, celestite, manganese and fluorite. Future plans include the extension of the regional gravity surveys in northern and eastern Cape Breton, the production of a new series of gravity maps for Nova Scotia including both Bouguer and residual anomaly maps, and a detailed study of the Chedabucto fault which runs east-west across the province and may continue seaward into the Atlantic.

During the last few years a computer oriented data handling system has been developed and is now in routine use. Data reduction, sort, merge, update, search and retrieval programs are in use. Plotting and interpretation programs are also available and a contouring package is presently being tested. All existing gravity data in Nova Scotia are gradually being incorporated in the data file.

Precise levelling methods used at present will be supplemented in 1971 by a hydrostatic levelling device currently

*Sheridan, R.E., and C.L. Drake. 1968. Seaward extensions of the Canadian Appalachians. *Can. J. Earth Sci.*, 5, 337-373.

under development. This device should find practical application in surveys involving loops or closures of distances up to a few miles.

University of New Brunswick

The Department of Surveying Engineering at the University of New Brunswick has completed a regional gravity survey of the province of New Brunswick and published eight Bouguer anomaly maps with 5 mgal contours at a scale of 1:250,000. Listings of 4,000 stations are also available. Professor K.B.S. Burke has commenced a geological interpretation of these results. Additional gravity observations have since been made as part of a program of the New Brunswick Department of Mines to map gravity lows associated with evaporite deposits in the Plumweseep-Penobsquis area.

Free-air anomaly maps have also been compiled and were used to calculate gravimetric deflections of the vertical at four triangulation stations in the province. These deflections were compared with astro-deflections. E.J. Krakiwsky has analyzed existing astrogeodetic deflection data in Canada. The objective of this analysis is to compute geoidal profiles using gravity data to interpolate deflection values between astrogeodetic stations.

Krakiwsky also reports that the satellite geodesy team at the University has made significant progress in defining the geodetic positioning of Canada's vast and remote land and sea areas. A satellite observing experiment was organized in November, 1970 in eastern Canada where seven satellite receivers (five on land, two at sea) simultaneously observed the doppler shift to five satellites in polar orbit. Simultaneous data was achieved for approximately 30 passes in a few days. The amount and type of data collected may be second only to that obtained in the U.S.A. The project was a joint program with Shell Canada Ltd. and Bedford Institute. The 60,000 feet of punched paper tape containing the data is now at the University for analysis. A mathematical model for the solutions of the positioning problem has been developed and programmed on an IBM 360/50 computer. Datum shift components between the geometric centre of the N.A.D. 1927 ellipsoid and the centre of gravity of the Earth will be determined from the data obtained in the experiment.

McGill University

At the Department of Mining, Engineering and Applied Geophysics, McGill University, four theses on different aspects of gravity have been completed in the four-year period 1967-1970. Theoretical formulae for the gravity effect of multiple horizontal semi-infinite blocks, truncated by a dipping plane, have been developed (B. Sharma, unpublished thesis, 1968; Sharma and Geldart, 1968) and the results checked over several two-dimensional faults in the St. Lawrence lowlands.

M. Vyas (unpublished thesis, 1969) has studied gravity anomalies over semi-infinite tilted slabs. The effect of tilt angle on semi-infinite blocks was calculated. It was necessary to terminate the block at finite depth. Extension of the results to calculate the effect of two-dimensional anticlinal and synclinal features was carried out by dividing the cross-section into several horizontal and tilted slabs.

H.P. Parsneau (unpublished thesis, 1970) studied two dimensional digital operations for filtering potential field data. The collection and manipulation of gravity and magnetic data in applied geophysics can be described in terms of sampling and filtering of continuous two-dimensional waveforms. Use of filter theory and modern processing techniques allows a more accurate approximation of potential field operations. The inverse Hankel transform and a wavelength filter were used for derivation of zero phase two-dimensional field operations.

A new approach for making terrain corrections using terrain profiles was described by W.B. Chang (unpublished thesis, 1970). The method is based on a simple formula for a three-dimensional shell in cylindrical co-ordinates. The terrain effect is calculated by superimposing a special graticule upon the terrain profiles and counting graticule elements. Results obtained were compared with results obtained by conventional methods and agreed within 0.1 mgal. The new approach is faster than previous methods employing graticules.

University of Manitoba

Gravity studies at the University of Manitoba have been concentrated mainly in the Rice Lake area of Manitoba. These investigations cover an area of some 2,000 km^2 and form part of Project Pioneer a joint geophysical-geological study by the Manitoba Mines Branch and the University.

The southern part of this area is underlain by granitic gneisses of the English River gneissic belt which appear to be in fault contact with rocks of the Rice Lake greenstone belt lying to the north. The Rice Lake volcanic-sedimentary belt has been intruded by several igneous bodies, only one of which, southeast of Gold Lake, is completely surrounded by greenstone. The rocks of the gneissic belt exhibit a completely different metamorphic history to those of the greenstone belt and also have entirely different structural characteristics. The juxtaposition of the two-rock types undoubtedly indicates some major dislocation.

A total of 1,260 gravity stations has now been established in the Rice Lake area. The gravity station distribution is not uniform and depends on a combination of accessibility and identification of critical areas. All of the gravity data observed to date have been reduced to Bouguer anomalies using a density of 2.67 g/cm^3.

Determination of densities of surface rocks forms an important phase of the work. Two methods are being used; determination from surface samples, and short detailed gravity traverses across outcrops with good relief to determine the average density of major rock units.

Interpretation of anomalies and preparation of final Bouguer anomaly maps is now underway. Some of the results have been published by Brown (1968) and by Hall and Hajnal (1969).

All available gravity data in Manitoba have been compiled at the University and a preliminary draft of a new gravity map of the province is in the editorial stage.

University of Alberta

The University of Alberta completed a gravity survey of an area of about 40,000 km^2 centred near Brooks in southern Alberta. Seismic reflection-refraction studies have led to the discovery of a rift valley, bounded by faults, at depths between 30 and 50 km in the lower crust (Kanasewich, 1966, 1968). This feature strikes nearly east-west. Gravity and magnetic surveys were used to follow the structure beyond the area of the detailed seismic study. Recently mapped magnetic anomalies show that it continues under the Rocky Mountains into British Columbia. The gravity anomalies have been shown to support the seismically-discovered rift structure, on a two-dimensional calculation.

A gravity survey made by the Dominion Observatory in the Stoney Rapids area of northern Saskatchewan is described by Agarwal and Kanasewich (1968). A major positive anomaly is underlain by a norite intrusion with an estimated anomalous mass of 10^{16} kg. A simple three-dimensional model was constructed for this mass distribution. In this model the norite outcrop in the northwest is gently dipping under the sandstone, and the main norite body is about 7 km thick in the centre with a sandstone layer almost 1 km thick on top of it. Considering the occurrence of economic minerals in the exposed part of the noritic rocks, it is suggested that several drill-holes in the sandstone area would enhance the geophysical interpretation of the main norite body and its economic importance for future development.

A method for automatic computer determination of geological or geophysical trends has been developed at the university using cross-correlation techniques. The trend direction is obtained by scanning cross-correlation coefficients and fitting a third degree polynomial equation to the selected contiguous maxima. The degree of correlation and the direction is obtained in a computer program that makes extensive use of logic statements and involves an interesting example of the possibility for programmed decision making. This study is described by Agarwal (1968).

Potential field data have been analyzed in a two-dimensional wave number domain to obtain the ratio of intensity of magnetization to the density (J/ρ) (Kanasewich and Agarwal, 1970). A two-dimensional fast Fourier transform was used to obtain auto-correlations, cross-correlations, convolution, upward continuation, vertical and horizontal derivatives and reduction of the total field to the pole. A coherency test was used on the two sets of data to evaluate the validity of the calculated J/ρ ratio for each wavelength. A high coherency value was assumed to arise if the gravity and magnetic anomalies are caused by the same body. A theoretical prismatic model and a field example from northern Saskatchewan were used to illustrate the techniques.

University of Calgary

At the University of Calgary F. Syber and P.E. Gretener are investigating the postulate that gravity anomalies are associated with deep seated reed structures. This project should be completed in 1971.

University of Saskatchewan

Gendzwill (1968, 1969a and b) completed a detailed survey and interpretation of gravity and density data in the Amisk Lake-Flin Flon region which covers an area of about 750 km^2 in east-central Saskatchewan. The main results include a Bouguer anomaly map, a density map and several new interpretation techniques (see also Gendzwill, 1970). The Bouguer anomalies correlate well with the densities of the Precambrian surface rocks and interpretation suggests that the surface density distribution must extend to depths of between 3 and 5 km to explain the gravity anomalies.

University of British Columbia

The University of British Columbia has published the results of a gravity survey of southwestern British Columbia covering an area of some 50,000 km^2 (Walcott, 1967). The Bouguer anomalies were divided into first- and second-order anomalies. Despite the obscuring effect of second-order anomalies the first order anomalies could be isolated to allow quantitative analysis. A positive anomaly over Vancouver Island and a negative anomaly over the Olympic Peninsula together define a linear anomaly pattern which was named the Coastal Anomaly. Using geological, seismic and gravity information, and the assumption of hydrostatic equilibrium, this feature was interpreted as the edge effect between two crustal blocks of different thickness and density. The model demonstrates that isostatic anomalies may arise through lateral variations in crustal density and thickness and need not indicate departures from equilibrium.

At the University of British Columbia the design and analysis of linear filters for the enhancement of potential field data have also been studied. Standard techniques such as regional/residual separation, second derivative computation and upward and downward continuation have been considered from the linear filter viewpoint. The effects of improved filters were examined (Clarke, 1969a and b, 1971; Ulrych, 1968, 1969).

Petroleum industry

The use of gravity surveying as a reconnaissance tool for petroleum exploration in Canada has recently increased significantly. During the last four years the average number of crew months has been 128 per year. This increased activity can be directly correlated with the shift in exploration to new frontier areas which include the Northwest Territories, the Arctic and the continental shelves. Large land holdings and difficult working conditions have stimulated the need for effective reconnaissance survey methods. Considerable effort is being made to solve logistical and operational problems in these remote areas.

Significant progress has been made in the use of computer-oriented data handling systems. Computers are now in routine use to reduce and interpret gravity data. More surveys completed by industry are being tied to the national gravity net established by Earth Physics Branch of the Department of Energy, Mines and Resources. Widespread use of gravity standards established by the Earth

Physics Branch ensures the long term value of oil company data.

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