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A COMPUTER-ORIENTED SYSTEM FOR THE REDUCTION OF GRAVITY DATA

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ABSTRACT:—In 1958, the Dominion Observatory expanded its program of regional and local gravity measurements throughout Canada. The regional observations are taken at intervals of 10 km using different makes of gravimeters, and transportation is provided by fixed and rotary-winged aircraft, automobiles and ships. The local surveys consist of detailed investigations of geological features and of areas in which steep horizontal gravity gradients are observed. The resulting increase in the volume of data (tenfold in about 5 years) required that a system of processing, filing and plotting of data from both types of survey be developed. The basic unit of the system is a computer program that reduces field observations to simple Bouguer and free-air anomalies, for use in both geodetic and geophysical investigations. The computed output data cards are maintained in a Principal Facts file, which is used to prepare Bouguer anomaly maps on an automatic plotter, and from which data is supplied upon request.

RÉSUMÉ:—En 1958, l'Observatoire fédéral a élargi ses travaux de mesures gravimétriques régionales et locales partout au Canada. On fait des observations régionales à tous les 10 km avec divers genres de gravimètres à l'aide d'avions, d'hélicoptères, d'automobiles et de navires. Les relevés locaux consistent en une étude détaillée des accidents géologiques et des régions où l'on observe des gradients gravimétriques horizontaux très prononcés. L'augmentation du volume des données (qui ont décuplé en cinq ans environ) a exigé la mise au point d'un nouveau système d'interprétation, de classification et de restitution des données que les deux genres de relevés permettent de recueillir. Ce système repose sur une calculatrice qui réduit les observations prises sur le terrain aux anomalies simples de Bouguer et à l'air libre pour utilisation en recherches géodésiques et géophysiques. Les cartes portant les renseignements sont conservées dans un Fichier des données principales, qui sert à préparer des cartes des anomalies de Bouguer à l'aide d'un restituteur automatique, et d'où on peut tirer des renseignements sur demande.

Introduction

In recent years the requirements for gravity data to assist with geological and geodetic studies have increased enormously. This is largely due to the ease of access to electronic digital computers making the calculation of such quantities as deflections of the vertical and the vertical gradient of gravity on a large scale quite feasible. However, to make the most of computers for such calculations it is extremely important that the basic data, whether free-air or simple Bouguer anomalies, be relatively error free, be on the same datum, and be filed in such a manner that all gravity information for any area under consideration is readily available. Therefore, a prime requirement for any scientific institution actively engaged in field programs to obtain regional gravity observations is a flexible system that not only computes the required gravity anomalies from field data, but also makes provision for revision of datum and cataloguing of the results.

The Dominon Observatory is the federal institution charged with the responsibility of conducting regional gravity studies in Canada. In addition, it acts as the central collecting and coordinating agency for gravity measurements made by other Canadian interests whenever transfer of such data is feasible. In order to carry out better the responsibility for distributing gravity data both nationally and internationally, a complete system for processing and handling gravity measurements has been developed at the Dominion Observatory over the past few years. The general procedures employed are based on a computer program written for an IBM 1620 computer equipped with card input-output, 40,000-digit storage capacity, and indirect addressing. The flow chart is shown in Figure 1.

In this paper the main features of the system are presented. Included are a brief description of the station numbering system, computation procedures complete with the equations used, and filing procedures. The discussion is concerned mainly with techniques used to process regional gravity observations made at intervals of about 10 km. Although the same procedures can apply generally to studies of geological features such as small intrusives, dykes and faults, it should be appreciated that compilation and filing procedures may vary considerably. Therefore the term "detail stations" as used here refers to regional work unless otherwise specified. Other terms used are "source deck" and "object deck" referring to the computer input and output respectively.

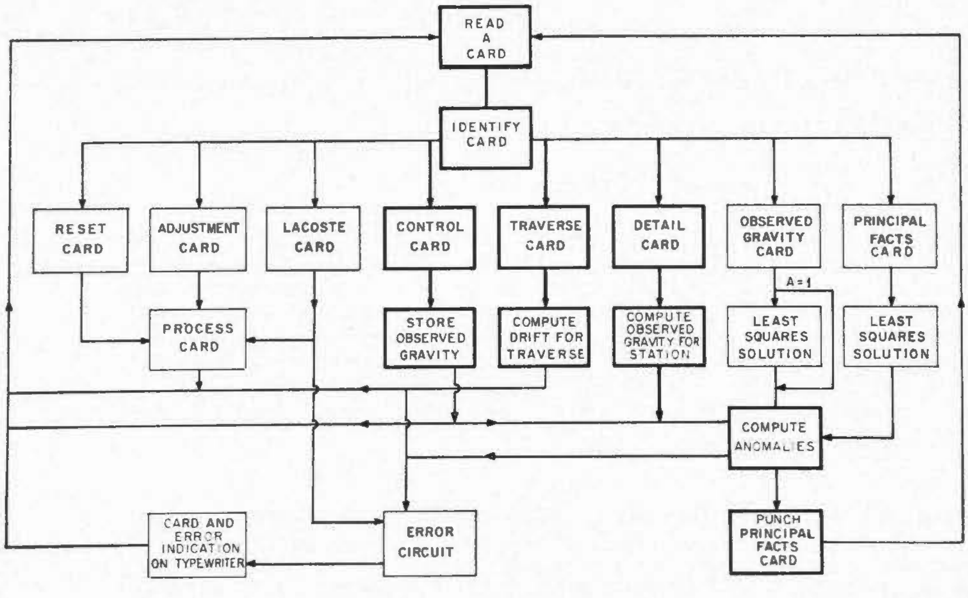

FIGURE 1

The flow chart for the computer program written to process gravity data.

Field Procedures

Current programs within the Dominion Observatory require that scientific personnel be sent to all parts of Canada under conditions that vary from those of the cold, rugged Arctic where aircraft are the main source of transportation, to those of the warmer, southern regions of Canada where standard passenger vehicles and surface ships are used for transportation. Accordingly, instrumental requirements vary from easily portable Worden gravimeters used with light aircraft, to underwater LaCoste and Romberg gravimeters used primarily to make gravity measurements in coastal waters. Because of the variety of instruments used and the different physical conditions encountered one rigorous survey procedure cannot be expected to apply to all surveys. However, in a general way all field parties follow the procedures given below.

Normally two types of gravity stations, control and detail, are established during the course of a regional gravity survey. Control stations that are used to provide the reference gravity values for the survey, fall into two general classes—primary and secondary. Primary control stations are observed using the well-known method of base-looping (Nettleton, 1940) and are inter-connected to form a series of closed circuits. As it is desirable that all control stations be on a common datum, the control network of the different surveys are interconnected, additional ties are made to pendulum stations, and finally an adjustment is made to form a national network of primary control stations. These sites are clearly marked and small-scale sketches drawn in order that the control stations may be reoccupied at some future date if necessary. The interval at which control stations are established varies from 40 km in populated southern regions to 150 km in uninhabited northern areas. Occasionally, extreme variations in the ambient temperature in northern areas result in high and erratic drift rates for the portable, unthermostatted Worden instruments, necessitating the use of secondary control stations intermediate to those of the primary network. These stations are established by traversing from primary control stations, taking single readings at desired sites with LaCoste and Romberg gravimeters. Since these instruments have excellent drift characteristics and since the time interval between readings at primary control points is restricted to less than three hours, the accuracy of gravity values for secondary control stations is comparable to that of primary control stations. Secondary control stations, however, are intended only for use during the particular survey and are not formally described.

A detail station may be defined as any single gravimeter observation taken relative to a control station in such a manner that the effect of instrument drift may be removed. Since the maximum desired error in the gravity value for any detail station relative to a control station is $\pm$ 0.25 mgal, the time interval between control-station readings for any detail-station traverse is determined by the drift characteristics of the particular instrument used. However, in the measurement of gravity at sea, extremely long time intervals between control-station readings are unavoidable, resulting in increased uncertainty in the relative gravity value for the detail station.

Wherever possible gravimeter readings are taken at bench marks or other well defined pointed of elevation, but, as much of Canada is accessible only by aircraft, such a requirement cannot always be met and elevations must be determined in many cases by using altimeters.

Water depths are obtained by a wire sounder or echo sounder and ice thicknesses are usually determined by seismic methods. Station locations are marked on maps and/or mosaics or are recorded using a navigational system such as Decca from which the geodetic coordinates can be computed. Normally the latitude and longitude of these stations are recorded to the nearest 0.1 minute of arc.

To complete the field operations data sheets are prepared to facilitate the preparation of punch cards using the formats shown in Figures 2, 3, and 4 which provide a sample of the manner in which traverse data are assembled. Thus the field personnel involved can thoroughly check the data and forward them to the computing section for processing in a relatively short interval after the completion of the survey. Figure 5 illustrates the output or object format and the sample data contained on the card are based on the traverse data given in Figures 2, 3, and 4.

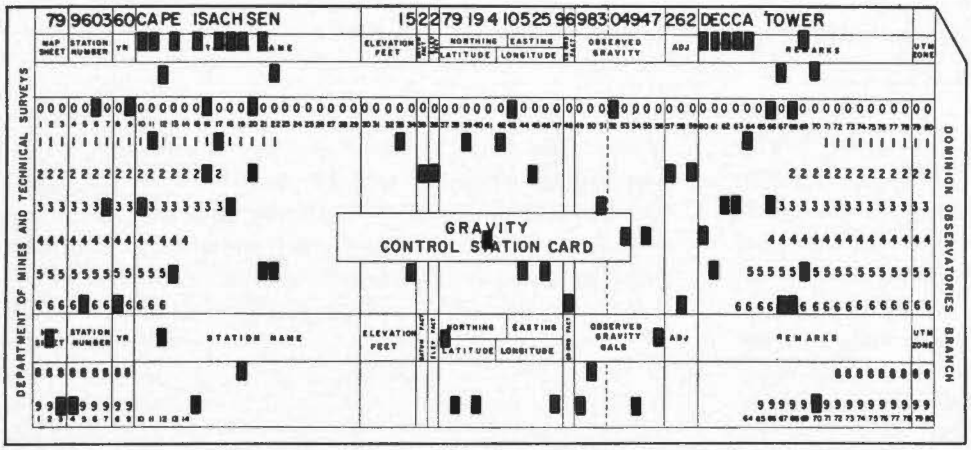

FIGURE 2

The control card. The color code for this card is blue.

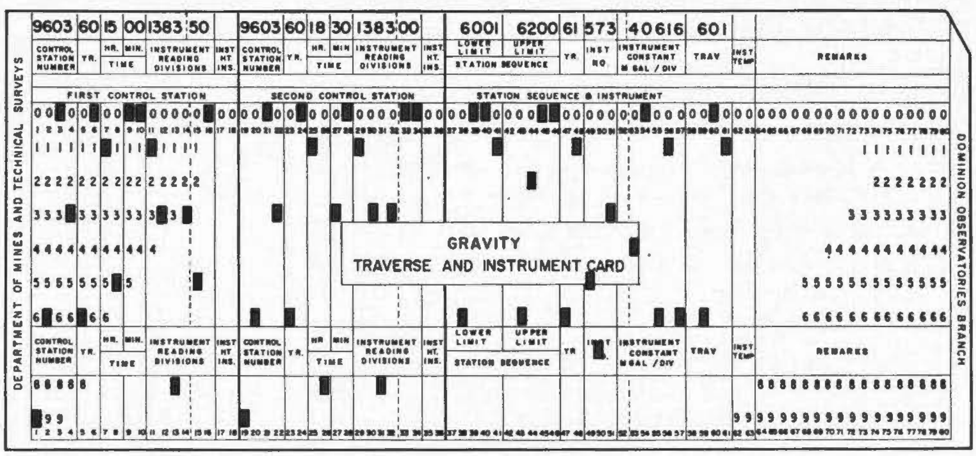

FIGURE 3

The traverse card. The color code for this card is green.

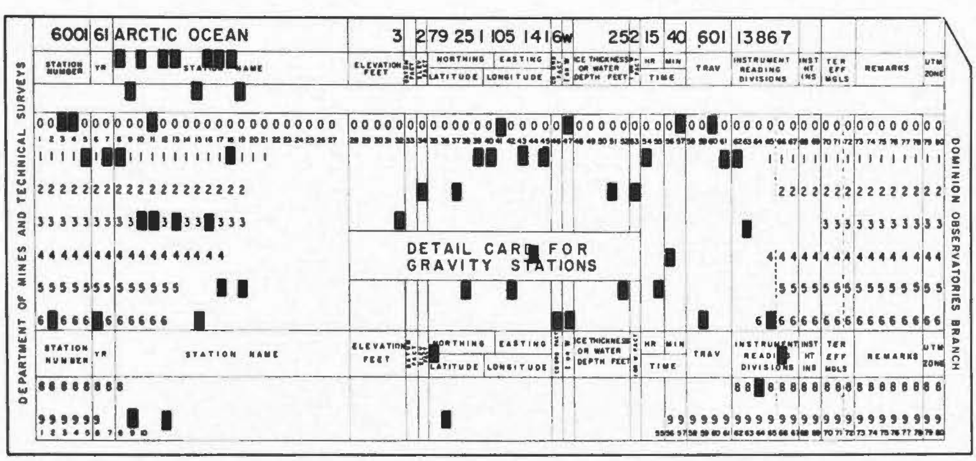

FIGURE 4

The detail card. The color code for this card is white.

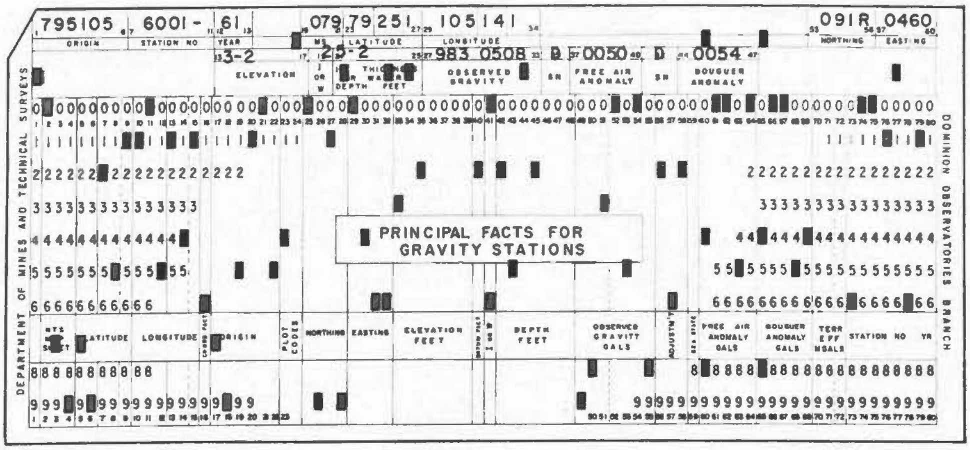

FIGURE 5

The Principal Facts card. The color code for this card is red. Note that the elevation, depth, and station number are left adjusted in their respective fields. The letters in the sign columns of the anomalies represent plus signs, and are necessary for the selection of this symbol by the plotter. Letters in the units positions of the northing and easting are caused by the combination of a minus (11) punch and the units digit in the same column.

The foregoing discussion has been concerned mainly with regional gravity observations. For detailed gravimetric studies, provision has been made on the detail and observed gravity cards for the use of the Universal Transverse Mercator (UTM) coordinate system in place of the latitude and longitude. Station locations can be recorded to the nearest ten metres, allowing for a more accurate determination of position and correspondingly greater accuracy in reduction of the data. When UTM coordinates are used the latitude and longitude are calculated within the computer and put out on the Principal Facts cards.

Station-Numbering System

In addition to several field programs within the Dominion Observatory group, data are received from other scientific institutions and from commercial interests in both the mining and petroleum industries. Since all data, when processed, are entered into a common data file, some system of distinguishing the source of any particular gravity station must be available. Also, a ready means of distinguishing control and pendulum stations should be a prime consideration in laying out the system. This, of course, can be accomplished in a variety of ways but one of the most effective is a comprehensive numbering system for gravity stations. Accordingly, at the Dominion Observatory all projects are assigned a sequence-of-station number as shown in the sample index given in Table I. The station number as entered on the data cards (Figures 2 and 4) is composed of two parts, (a) the number assigned chronologically within the particular sequence and (b) the year the observations are made or received by the Dominion Observatory. So that the various types of stations may be recognized the following additional divisions are made:

i) control stations are assigned a number of the form 9XXX-XX
ii) pendulum stations are assigned a number of the form 99XX-XX
iii) detail stations are numbered in the form XXXXX-XX with the digit "9" not permitted in either the first or second position of the station number.

In each instance the last two digits refer to the year of the observation. Except for pendulum stations the first two digits of each number may be used as a reference to the instrument used, area of survey, and other information given in Table I. This simple means of

TABLE I

Sample Index of Station Sequence for 1962

Area	*Party*	*Instruments*	*Detail Station Sequence*	*Control Station Sequence*	*Traverse No.*	*Remarks*
Polar Continental Shelf Project	L. W. Sobczak	LaCoste G-25	00001—01000	——	0001—0100	
		Worden 573	01001—02000	9001—9200	0101—0200	
		Worden 460				Spare instr.
Baffin Island	J. R. Weber	LaCoste G-7		9201—9500	0921—0950	
		Worden 431	02001—03500	——	0201—0350	
		Worden 546	03501—05000	——	0351—0500	
		Canadian 132	——	——	——	Spare instr.
Western Canada	ABC Oil Co.	——	10001—12000	——	——	Observed gravity values only

identification permits extension of the numbering system for international use by including, on the Principal Facts cards, a three- or four-digit alphameric field referring to the country in which the data originated.

The number given to control and pendulum stations has been restricted to four digits plus the year because it has been found in practice that specific stations are frequently referred to by number rather than by geographic name. A five-digit number, as used for all other stations, has been found to be cumbersome and difficult to remember.

Referring to Table I it can be seen that the general practice, wherever possible, is to assign detail station numbers of less than 10,000 to Dominion Observatory projects. Indeed, only rarely has it been necessary to assign numbers in access of 10,000 as the general practice has been to allot a sequence that is slightly greater than estimated for any particular project. Thus, at the conclusion of the main field programs there are usually sufficient unused blocks of numbers available to satisfy the requirements of other minor projects.

Processing Data

General Procedures

Although data are received from other sources in a form different from that of traverse data (Figure 6) and provision is made within the program to process this information, about 90 per cent of the computer operation is taken up with the calculation of free-air and Bouguer anomalies from traverse data. Accordingly, emphasis is placed on procedures used to process such data and, except when required, no description is provided for other branches in the flow diagram (lighter face) of Figure 1.

Upon completion of the field program the observational data are placed on the appropriate punch cards (Figures 2, 3, and 4) and the source deck, consisting of control cards followed by traverse and detail cards, is assembled. These latter are merged mechanically by sorting on the traverse number (Figures 3 and 4). At this stage a thorough check is made of the source deck for both general order and for transcribing and punching errors. This phase is greatly facilitated by a color-code that has been adopted for each data card and also by a print-out or interpretation of the perforations on each card as shown in Figures 2, 3, and 4. When the check has been completed, a card is placed in front of the source deck, which indicates to the computer the nature of the reduction and hence the general flow of the program.

The computer operation proceeds along the lines indicated in Figure 1. The arithmetic operations are based on the equations given subsequently. There is, however, one aspect of the operation—namely, the error indications given on the typewriter—that is worthy of particular mention at this point. The tests for errors made by the program fall into two general classes, editing and gross errors in the data. Editing checks involved tests to determine whether a particular computation can be logically executed. For example, upon reading and identifying a detail card the computer checks that the reading, time of reading, station coordinates, elevation and other required information has been properly recorded and that this information is consistent with the traverse card data. Gross errors for which the computer is programmed to test include excessive drift rates, unusually large gravity differences and other similar errors. When an apparent error is located the program instructs the computer to give the error indication on the typewriter as well as a reference to the particular data card and, if computations are involved, the magnitude of the error. The existing version of the program contains provision for about 40 possible errors.

The initial processing of the traverse data is carried out on the computer with no card output. This editing run is intended to produce only error indications on the typewriter. These error indications must be checked, corrections made to the input data as necessary, and the

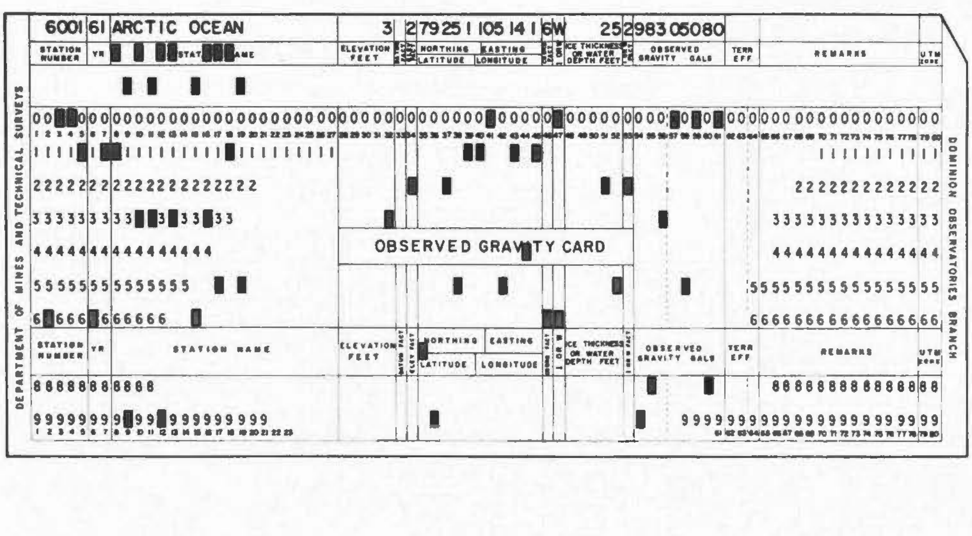

FIGURE 6

The observed gravity card.

corrected data recomputed with card output. The resulting Principal Facts cards are then sorted in preparation for plotting the Bouguer anomalies.

The system of sorting and filing of the Principal Facts cards is oriented toward the use of an automatic data plotter. Since latitude and longitude coordinates are non-linear, a system of rectangular coordinates such as the Universal Transverse Mercator system must be used to plot the station locations. Because standard plotters can accept a maximum of four digits in the abscissa and ordinate, the basic map-plotting unit is one degree of latitude by two degrees of longitude, or a 1:250,000-map sheet on the National Topographic System for Canada. Maps of all scales can be prepared by combining or subdividing these units. The location of any station is given as a northing and easting, to the nearest ten metres, from the origin point at the centre of the map unit.

For permanent storage the data cards contained within each map unit are inserted, in sequence, into a file known as the Principal Facts file. The map units are arranged by origin number (Figure 5) which is obtained from the latitude and longitude of the origin. Although this file uses the UTM coordinate system, the latitude and longitude of the station are retained on the Principal Facts card for purposes of checking maps and as a basis for geodetic and other computations. At present, only a card file is maintained. However, when the volume of cards becomes very large, it will be necessary to use digital magnetic tape to store the information.

Computation Procedures

As was pointed out in the introduction the aim of this system is the production of a file of basic gravity data for use in both geophysics and geodesy. Consequently only standard reduction procedures are used to obtain the Bouguer and free-air anomalies and although the methods used here are listed in geophysics texts in one form or another, a résumé has been included for convenience. The vertical gradient of gravity is assumed to be 0.09406 mgal/foot and the crustal, ice and water densities are assumed to be 2.67, 0.90 and 1.03 gm/cc respectively. Bouguer anomalies are computed assuming the topography to have the form of an infinite sheet having a thickness equal to the height of the gravity station above sea level. For stations located over glacial ice or water-covered regions, the reduction is carried out by assuming the body of ice or water to have the form of an infinite sheet and replacing it with standard crustal material during the Bouguer reduction.

No provision has been made to compute the terrain effect because there are insufficient topographic data available for many parts of Canada and because the volume of data required to put the computations on a routine basis far exceeds the capacity of small computers such as the IBM 1620 used for this problem. At the same time it can be pointed out that, as the relief in most of Canada is relatively low, the effect of terrain is generally less than one mgal and it is doubtful whether it is necessary to undertake such an enormous and expensive project such as the routine computation of the terrain effect for most of the interior of Canada. However, in the mountainous regions along the eastern and western coastlines the effect of topography may be as large as 20 mgal. Therefore, if gravity observations in these regions are used for geological and isostatic investigations, corrections for this effect must be determined either by the use of templates (Nettleton, 1940) or by assuming the topography to have some geometric form such as a raised triangular strip. This is very tedious and time-consuming and it is hoped than an investigation currently under way will permit the evaluation of terrain effects in mountainous regions using very large computers.

In the program a special case is provided for underwater measurements made with a LaCoste and Romberg gravimeter operated by remote control from the deck of a surface ship. As the instrument is read on the sea floor and as it is customary to refer gravity observations to the water surface, the observed gravity value is transformed to an equivalent surface observation by applying the free-air effect and a double Bouguer correction for the body of water. All subsequent corrections applied to these data are similar to those made for other observations.

The equations used to obtain the observed gravity values from the gravimeter readings and the free-air and Bouguer anomalies are listed below*.

(*i*) *Temperature effect on Worden instruments*

When these instruments are operated without a temperature-control unit the scale constant varies with temperature as follows:

$$K = K_{cal} - 0.000072\,(75 - T)\,K_{cal} \qquad (1)$$

where K is the corrected scale factor, K_{cal} the instrument constant determined from the calibration line or tilt table, and T the instrument temperature in degrees Fahrenheit. The constant 0.000072 is provisional pending final results of a series of experiments conducted at the Dominion Observatory (Hamilton, personal communication).

*The use of symbols within these or other equations in the text is uniform throughout and, therefore, each symbol is defined only when it first appears.

(ii) Drift rate

For the computation of the drift rate a linear relationship with time is used. For precise work the time interval between readings at control stations is usually kept to less than three hours.

$$\sigma = \frac{(R_{cs1} - R_{cs2}) + \dfrac{(g_{cs1} - g_{cs2})}{K}}{t_{cs2} - t_{cs1}} \qquad (2)$$

where σ is the drift rate, R_{cs1} and R_{cs2}, g_{cs1} and g_{cs2}, and t_{cs1} and t_{cs2} are respectively the readings, gravity values and times of readings at the first and second control stations.

(iii) Observed gravity for detail stations

$$g_s = g_{cs1} + K\left((R_{cs1} - R_s) + \sigma\,(t_s - t_{cs1})\right) \qquad (3)$$

where g_s is the observed gravity value, R_s is the reading, and t_s is the time of reading at the particular detail station.

(iv) Theoretical gravity or latitude effect

The reference spheroid used at the Dominion Observatory is the International ellipsoid of 1930 given by the equation

$$\gamma_t = 978.049\,(1 + 0.0052884 \sin^2 \varphi - 0.0000059 \sin^2 2\,\varphi) \qquad (4)$$

where γ_t is the theoretical value of gravity and φ is the latitude of the station.

(v) Free-air anomaly

This anomaly is computed for geodetic use and recent theoretical developments (Nagy, 1963) require the free anomaly at the surface. This is accomplished by taking the difference between the measured value at the topographic surface and the theoretical value which is extrapolated from the reference ellipsoid.

The general expression is given and particular solutions can be obtained by setting the quantities not involved to zero. The equation is

$$\Delta g_{FA} = g_s - \left(\gamma_t - \frac{dg}{dz} h\right) - \left(\frac{dg}{dz} - 4\,\pi\,G\,\rho_w\right) d_w \qquad (5)$$

where Δg_{FA} is the free-air anomaly, dg/dz is the vertical gradient of gravity, h is the station elevation, G the universal constant of gravitation, w the density of water, and d_w the depth of water.

(vi) Bouguer anomaly

The Bouguer anomaly is intended for use with geological investigations and is determined using the equation

$$\Delta g_B = g_s - \gamma_t + \frac{dg}{dz} h - 2\,\pi\,G\,\rho_c h + 2\,\pi\,G\,(\rho_c - \rho_w)\,d_w + 2\,\pi\,G\,(\rho_c - \rho_i)\,d_i - \left(\frac{dg}{dz} - 4\,\pi\,G\,\rho_w\right) d_w \qquad (6)$$

where Δg_B is the Bouguer anomaly, ρ_c is the assumed crustal density, ρ_i is the assumed density of ice, and d_i is the thickness of ice.

(vii) Map-sheet number

The map-sheet number (Figures 2 and 5) is based on the National Topographic System which divides all Canada south of latitude 80°N into areas of 4° of latitude by 8° of longitude. The boundaries of the NTS map sheets coincide with those adopted by International Civil Aeronautics Organization for the 1:1,000,000 series of maps. North of latitude 80°N, because of the convergence of the meridians, the division into map sheets is based on 4 degrees of latitude and 16 degrees of longitude. For any station south of 80°N the map-sheet number can be determined using the formulae

$$D_{12} = \frac{\lambda^\circ - 48^\circ}{8^\circ} \qquad (7)$$

and

$$D_3 = \frac{\varphi^\circ - 40^\circ}{4^\circ} \qquad (8)$$

where D_{12} are the first and second digits of the map-sheet number, D_3 is the third digit of the map-sheet number and φ° and λ° indicate the degree square in which the station is located. All decimals are dropped in the calculations. North of latitude 80°N the map-sheet number cannot be generated from these equations and is assigned individually by the computer on the basis of the coordinates.

Changing Datum

Improved instrumentation as well as an increased number of observations necessitate periodic revision of local, national and international gravity networks. To obtain the best values of gravity for the stations in a control network two steps are usually required, namely, the accurate calibration of the gravimeters *vs.* some standard gravity interval and the adjustment of circuit misclosures using a method of least squares. If the change in the gravity standard is one of calibration only, the program provides for this according to the equation

$$g_{cs} = (1 \pm F)(g_p - g_u) + g_p \qquad (9)$$

where F is the factor expressing the calibration change, g_p is the value of gravity at the National Reference Station, and g_u is the unadjusted gravity value for the control station. This modification is accomplished by providing the computer with the quantities F and g_p and reprocessing the traverse data. In addition to preparing new Principal Facts cards, the computer punches out control and traverse cards containing the corrected gravity values and scale constants respectively. On the other hand, if new information requires that the observation equations be changed, the entire network must be re-adjusted and new control cards prepared.

A constant datum change is effected using the relation

$$g_{cs} = g_u \pm D \qquad (10)$$

where D is the constant correction required to adjust the control station gravity value.

In cases where the data are very old and many of the control stations are either destroyed or cannot be relocated it may not be feasible to reprocess the original traverse data. In this situation provision has been made for the application of the least-squares solution to the principal facts data. This is usually done by re-occupying about 10 per cent of the stations to provide the new datum or standard for the old data. The gravity values are adjusted to fit the new datum using the equation

$$g_s = Ag_u + B \qquad (11)$$

The quantities A and B, which are the slope of the line giving the best least-squares fit and the y-intercept respectively, can be determined using the equations

$$A = \frac{\Sigma\, g_u \Sigma\, g_o - n\, \Sigma\, g_u\, g_o}{(\Sigma\, g_u)^2 - n\, \Sigma\, g_u^2} \qquad (12)$$

and

$$B = \frac{\Sigma\, g_u \Sigma\, g_u\, g_o - \Sigma\, g_u^2\, \Sigma\, g_o}{(\Sigma\, g_u)^2 - n\, \Sigma\, g_u^2} \qquad (13)$$

where n is the number of stations used in the least squares solution and g_o is the observed gravity value according to the current datum in use at the Dominion Observatory. The standard error of estimate (S) for the least-squares solution is given by the expression

$$S = \sqrt{\Sigma\, g_o^2 - A\, \Sigma\, g_u\, g_o - B\, \Sigma\, g_o/(n-2)} \qquad (14)$$

A large part of the data obtained from sources outside the Dominion Observatory is received with the observed gravity values already calculated. As this material is generally on a datum different from that accepted by the Dominion Observatory, a least-squares solution must be applied using equations 11, 12 and 13 as indicated in Figure 1. As there is considerable difficulty in relocating sites of these gravity stations on the basis of coordinates alone it has, in some cases, proven difficult to obtain a satisfactory least-squares solution on the basis of a nominal number of station reoccupations.

Conclusion

The main features of a computer-oriented, punch-card system for general gravity reductions have been presented along with a brief discussion on each major division of the project. Based on the experience gained during a five-year period of development the following major requirements for such a system are given:

1. Particular care must be taken to reference properly the object deck with the source data.
2. Provision must be made to adjust the gravity results quickly in accordance with a datum change.
3. The corrections applied to the observed data in computing the free-air and Bouguer anomalies should be made as simple as possible. As these quantities are used for numerous other calculations, complex reduction procedures that are usually to some extent interpretative, may tend to obscure the accuracy and possibly even the significance of the end result.
4. Wherever possible, factors such as those given in Appendix A, indicating the accuracy or the source of the data should be assigned to the elevation, geographic coordinates and the water depth or ice thickness. When using the anomalies to calculate gradients or plumb-line deflections the quality of the source data should be known in order to assess properly the significance of the computed result.

APPENDIX A

Contained on the data cards shown in Figures 2, 3, 4, and 5 are factors that indicate either the quality or the source of the work. A brief description of the purposes and the basis used to assign the factor is given below:

a) Datum factors

This factor is used when working with altimeters and indicates the source of the reference elevation for the altimeter traverse.

This classification is as follows:

1. Spirit level.
2. Other altimeter or radar altimeter.
3. Arbitrary.

b) Elevation

This classification is based on the estimated accuracy of the elevation as follows:

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

c) Coordinate factor

This is assigned on the basis of the source of the geographic coordinates as follows:

1. Coordinates scaled from 1:25,000 map
2. Coordinates scaled from 1:50,000 map
3. Coordinates scaled from 1:125,000 map
4. Coordinates scaled from 1:250,000 map
5. Coordinates scaled from 1:500,000 map
6. Coordinates obtained by instrumental means (Decca, star shots, etc.)
7. Coordinates from other sources.

d) Depth factor

The depth factor follows the same scheme as does the elevation factor:

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

e) Datum number

This quantity provides a reference to the datum or adjustment on which the observed gravity values are based. It is a three-digit number with the last two digits referring to the year of the adjustment.

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