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THE ESTABLISHMENT OF GRAVITY BASES AT AIRPORTS ACROSS CANADA

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HUDSON BAY
ATLANTIC OCEAN
I
II
III
IV
V
VI
FORT ST. JOHN
GRANDE PRAIRIE
PRINCE GEORGE
DOG CREEK
EDMONTON
VERMILION
VANCOUVER
PRINCETON
CALGARY
SASKATOON
GRAND FORKS
CRANBROOK
LETHBRIDGE
MEDICINE HAT
SWIFT CURRENT
REGINA
YORKTON
NEEPAWA
BRANDON
PORTAGE LA PRAIRIE
WINNIPEG
KENORA
SIOUX LOOKOUT
ARMSTRONG
NAKINA
KAPUSKASING
TIMMINS
GRAHAM
MARATHON
PORT ARTHUR
SAULT STE. MARIE
SUDBURY
NORTH BAY
OTTAWA
TORONTO
TRENTON
MONTREAL
QUEBEC
MEGANTIC
BAIE COMEAU
CHATHAM
CHARLOTTETOWN
MONCTON
AMHERST
FREDERICTON
SYDNEY
STEPHENVILLE
GANDER
128°
120°
112°
104°
96°
88°
80°
72°
64°
56°
52°
48°
44°
40°

The Establishment of Gravity Bases at Airports Across Canada

A. M. BANCROFT

ABSTRACT—Three gravimeters were transported in a chartered aircraft to make observations at 48 airports in all ten provinces by the method of forward looping.

The established network formed six closed circuits in order to allow subsequent adjustment. Observations for each instrument were adjusted separately by a tabular iteration method which is described in detail. This approach provides a least-squares solution much more readily than either the formal method or the graphical technique.

Instrument calibration constants were derived by comparison of the observations with Cambridge pendulum data. The gravity differences were weighted and combined and a final solution obtained by a further tabular iteration. Finally, all gravity values are listed relative to the adopted value for the National Reference Pier in Ottawa.

The standard deviations of the observations are estimated by a method of intercomparison to range from 0.2 milligal for stations near Ottawa to 0.5 milligal for stations in Western Canada.

A complete tabulation of the observations and adjustments is included, together with detailed station descriptions.

RÉSUMÉ—On a nolisé un avion pour transporter trois gravimètres utilisés en vue de faire des observations à 48 aéroports répartis dans les dix provinces canadiennes suivant le procédé des mailles progressives ou lectures répétées (AB – BA – AB – BC – CB).

Le réseau établi comprend six circuits fermés qui permettront des ajustements subséquents. Les données fournies par chaque instrument ont été revisées séparément suivant une méthode d'itération tabulaire décrite en détail dans la présente publication. Cette façon de procéder fournit une solution suivant la méthode des moindres carrés qui est beaucoup plus rapide que la méthode formelle ou la technique graphique.

Les constantes de calibration des instruments ont été obtenues grâce à la comparison des données obtenues avec celles du pendule de Cambridge. On a évalué et combiné les différences des valeurs de la gravité, et une dernière itération tabulaire a fourni une solution définitive. Finalement, on énumère toutes les valeurs gravimétriques telles que comparées à la valeur adoptée pour le pilier national de référence (*National Reference Pier*), à Ottawa.

Les déviations ordinaires des observations sont déterminées suivant une méthode d'intercomparaison; elles varient de 0.2 de milligal, dans le cas des stations situées près d'Ottawa, à 0.5 de milligal, dans le cas de stations situées dans l'Ouest canadien.

On donne un tableau complet des observations et des ajustements, ainsi que des descriptions minutieuses des stations.

Introduction

In the summer of 1955, gravity base stations were established at 48 airports across Canada using three gravimeters and aircraft transportation. The stations were connected by the method of forward looping, the operation beginning and ending at Vancouver.

Figure 1 shows the approximate location of the stations, and the fact that all stations except Vancouver and Gander form part of six closed circuits. From the closure errors around these circuits it was possible to estimate the accuracy of the observations, and to adjust the results.

The two-man gravity party left Ottawa by train on June 6, and returned 62 days later. Of the 53 days when the operation was in progress, 13 were lost on account of bad weather, 7½ were spent on repairs to the aircraft and 5 were spent in Ottawa. On four occasions looping was interrupted (twice by weather and twice by mechanical difficulties with the aircraft) and had to be repeated. In all, some 25,400 miles were flown and a rough log showed that just over 200 hours were spent in the air.

The aircraft used was a twin-engined Beechcraft type A-18A (CF-BQH) on charter from Pacific Western Airlines. The writer is indebted to the captain of the aircraft, Mr. R. J. Oliver, and his engineer Mr. J. Hutchinson, not only for the skill with which they performed their own duties, but also for their cheerful cooperation at all times. F. de Forrest (now graduated from the University of Manitoba) assisted, and also helped with the initial reduction of the data.

The Observations

The instruments used were a North American gravimeter (No. 137) and two Worden gravimeters (Nos. 44 and 192). Worden gravimeter No. 44 was fitted with a constant temperature enclosure in an attempt to improve its response to temperature "shocks". Both Worden instruments were equipped with extended-range reading dials.

At each airport a site was chosen which was accessible by car, and at many stations, connections were made to gravity stations previously established by the Dominion Observatory. In some cases, this was done by using one of the Worden instruments, but ties were also made by another Dominion Observatory crew.

At six stations, ties were made to nearby Cambridge pendulum stations (Garland 1955), thus allowing a calibration to be made over most of the range in gravity over which they were used.

The Adjustment of the Results

Before the calibration of the gravimeters could be attempted, the results for each instrument had to be adjusted until the closure error around any circuit was zero. The method of doing this is explained by taking the North American instrument No. 137 as an example.

For each leg of the network a value of the "unadjusted ΔR" was obtained, which had been corrected for the combined effect of diurnal change and instrumental drift by assuming a linear change between repeat readings. To each value of ΔR, an "adjustability" was assigned by inspecting the lack of parallelism of the drift curves. This "adjustability" can be thought of as the inverse of the "weight" attached to the value; it was usually either one (when the performance was very good), two, or three. In one case (Princeton to Dog Creek) the performance of instrument No. 137 was very poor, and an adjustability of 10 was assigned in the reduction.

Table 1a summarizes the results obtained with instrument No. 137, and can best be understood by reference to Figure 2, a diagrammatic representation of the network. The values of ΔR before adjustment are listed in the first column of Table 1a and a positive value in this column indicates an increase in gravity in a clockwise direction around a particular circuit. Figure 2 gives the closure error around each circuit in hundredths of scale divisions and the number of legs in each circuit. The method of adjusting these errors to zero is shown in Table 2a which also summarizes the data of Figure 2. As an example, the top line of Table 2a shows that circuit IV has a total adjustability of 12. This can be checked against Figure 2 or Table 1a, which shows that circuit IV is composed of six legs, of which one leg has unit adjustability, four legs have an adjustability of 2, and one leg has an adjustability of 3. The next line shows that circuit IV has a "linkage" adjustability with circuit III of 2, and a linkage adjustability with circuit V of 1. Again, this can be checked by referring to the network diagram, Figure 2. The next line in Table 2a lists the closure errors in units of hundredths of scale divisions. Here again, a positive value indicates a clockwise closure error.

The left-hand column of Table 2a next shows the adjustments which have to be made to each unit of adjustability in order to make the residual closure error as small as possible. To take circuit V as an example it is found on iteration that an adjustment of +3 per unit adjustability is needed, and since the circuit has an adjustability of 16, the adjustment to this circuit is +48. Furthermore, since circuit V has link adjustabilities with circuits IV and VI of unity, the effect of the adjustment to circuit V will introduce adjustments of −3 in circuits IV and VI.

In this way, the adjustments which have to be made to each circuit, in order to make the residual closure errors as small as possible, can be found by trial and error. The residual closure errors with which we are left in the present case are quite negligible but were in fact distributed among the legs with the greatest adjustability.

The solution obtained by this method should be equivalent to a least-squares solution if care is taken that the residual closure error around the whole network is also small. This quantity is simply the algebraic sum of the closure errors around the individual circuits, which is −8 in the example of Table 2a. The graphical method of network adjustment has been well described (Smith, 1951), but the tabular solution given here, although based upon the graphical method, is found to be much faster in practice. It can be recommended as a useful method of handling gravity or elevation data when the results of a survey are in the form of measured differences around interconnecting closed circuits.

The results obtained with the Worden gravimeters were treated in a similar manner. The circuit closures are shown on Figure 2, values of ΔR before and after adjustment are listed in Tables 1b and 1c, and the distribution of closure errors by the tabular method is given in Tables 2b and 2c. The only additional complication in the reduction of the data from the Worden instruments is the necessity of converting the differences in reading of the extended range reading dial to small dial differences. For each instrument this conversion involved the use of a table of values which had been computed by numerical integration of a curve showing the variation of the "large dial/small-dial

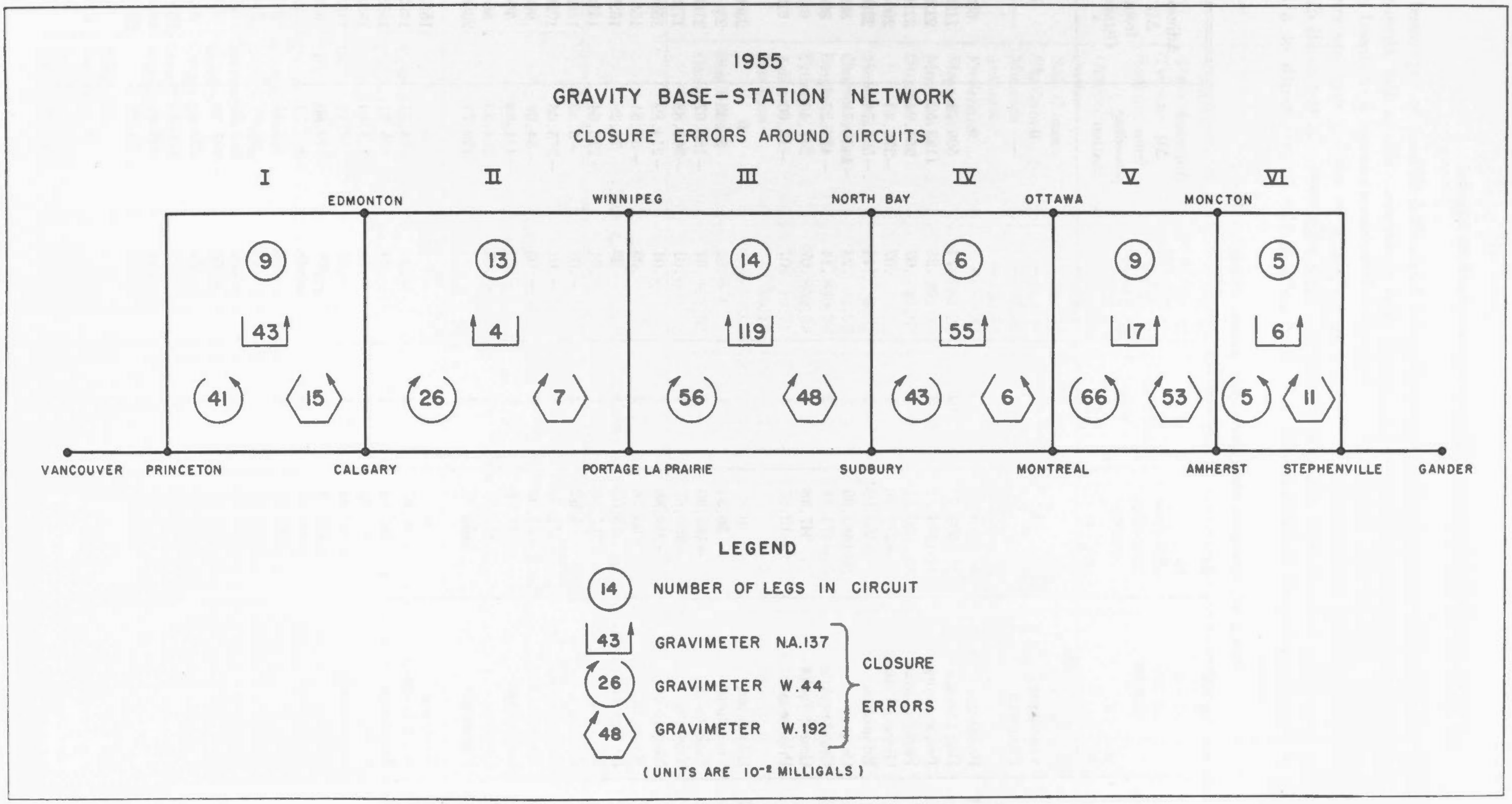
1955
GRAVITY BASE-STATION NETWORK
CLOSURE ERRORS AROUND CIRCUITS
I
II
III
IV
V
VI
EDMONTON
WINNIPEG
NORTH BAY
OTTAWA
MONCTON
9
13
14
6
9
5
43
4
119
55
17
6
41
15
26
7
56
48
43
6
66
53
5
11
VANCOUVER
PRINCETON
CALGARY
PORTAGE LA PRAIRIE
SUDBURY
MONTREAL
AMHERST
STEPHENVILLE
GANDER
LEGEND
14
NUMBER OF LEGS IN CIRCUIT
43
GRAVIMETER N.A.137
26
GRAVIMETER W.44
48
GRAVIMETER W.192
CLOSURE
ERRORS
(UNITS ARE 10^-2 MILLIGALS)

FIGURE 2

ratio" vs. large dial position. The curve itself was based on extensive laboratory measurements before and after the operation, together with several individual measurements of LD/SD ratio made at various latitudes.

The total difference in reading between two stations is the algebraic sum of the adjusted small dial difference plus the large dial difference expressed in equivalent small dial divisions. (Since the closure error of the large dial differences around any closed circuit was zero it was necessary to adjust only the small dial differences). The adjustment of the small dial closures was carried only to the nearest tenth of a division. This

TABLE 1a.—RESULTS OBTAINED WITH NORTH AMERICAN No. 137

Circuit	Station	ΔR from preceding station	Adjustability	Adjustment	Adjusted ΔR from preceding station	Adjusted ΔR from Ottawa
	Vancouver	0	—	—	0	0
	Princeton	—	—	—	—	—
I	Princeton	0	—	—	0	629.2
	Dog Creek	509.00	10	.74	509.74	1138.9
	Prince George	1183.31	3	.21	1183.52	2322.4
	Fort St. John	956.87	1	.07	956.94	3279.4
	Grande Prairie	−375.40	1	.07	−375.33	2904.0
	Edmonton	−595.88	2	.14	−595.74	2308.3
	Calgary	−1439.95	3	.24	−1439.71	868.6
	Cranbrook	−474.41	2	.14	−474.27	394.3
	Grand Forks	247.38	1	.07	247.45	641.8
	Princeton	−12.67	1	.07	−12.60	629.2
II	Edmonton	0	—	—	0	2308.3
	Vermilion	36.34	1	−.01	36.33	2344.6
	Saskatoon	−183.96	1	−.01	−183.97	2160.7
	Yorkton	−360.87	1	−.01	−360.88	1799.8
	Neepawa	−214.88	1	−.01	−214.89	1584.9
	Winnipeg	−33.78	2	−.03	−33.81	1551.1
	Portage la Prairie	75.05	1	.23	75.28	1626.4
	Brandon	−215.63	1	−.01	−215.64	1410.7
	Regina	−5.52	2	−.03	−5.55	1405.2
	Swift Current	−375.62	1	−.01	−375.63	1029.5
	Medicine Hat	−34.03	2	−.03	−34.06	995.5
	Lethbridge	−441.38	1	−.01	−441.39	554.1
	Calgary	314.53	2	−.03	314.50	868.6
	Edmonton	1439.95	3	−.24	1439.71	2308.3
III	Winnipeg	0	—	—	0	1551.1
	Sioux Lookout	−87.97	1	−.24	−88.21	1462.9
	Armstrong	195.55	1	−.24	195.31	1658.2
	Nakina	−124.25	1	−.24	−124.49	1533.7
	Kapuskasing	−67.91	1	−.24	− 68.15	1465.5
	Timmins	−540.16	3	−.70	−540.86	924.7
	North Bay	−903.24	2	−.48	−903.72	21.0
	Sudbury	217.96	2	−.02	217.94	238.9
	Sault Ste. Marie	36.23	1	−.24	35.99	274.9
	Marathon	916.49	3	−.70	915.79	1190.7
	Port Arthur	−368.49	3	−.70	−369.19	821.5
	Graham	120.73	1	−.24	120.49	942.0
	Kenora	494.68	2	−.47	494.21	1436.2
	Portage la Prairie	190.41	1	−.24	190.17	1626.4
	Winnipeg	−75.05	1	−.23	−75.28	1551.1
IV	Sudbury	0	—	—	0	238.9
	North Bay	−217.96	2	.02	−217.94	21.0
	Ottawa	−20.25	3	−.71	−20.96	0

TABLE 1a.—RESULTS OBTAINED WITH NORTH AMERICAN No. 137—*Con.*

Circuit	Station	ΔR from preceding station	Adjustability	Adjustment	Adjusted ΔR from preceding station	Adjusted ΔR from Ottawa
	Montreal	93.90	1	−.26	93.64	93.6
	Trenton	−586.45	2	−.46	−586.91	−493.3
	Toronto	−307.15	2	−.46	−307.61	−800.9
	Sudbury	1040.24	2	−.46	1039.78	238.9
V	Ottawa	0	—	—	0	0
	Quebec	497.96	3	.10	498.06	498.1
	Baie Comeau	962.37	3	.09	962.46	1460.5
	Chatham	−640.91	1	.03	−640.88	819.6
	Moncton	−397.07	1	.03	−397.04	422.6
	Amherst	−130.13	1	0	−130.13	292.5
	Fredericton	−9.45	2	.06	−9.39	283.1
	Megantic	−581.66	2	.06	−581.60	−298.5
	Montreal	392.10	2	.06	392.16	93.6
	Ottawa	−93.90	1	.26	−93.64	0
VI	Moncton	0	—	—	0	422.6
	Charlottetown	31.95	1	.03	31.98	454.6
	Stephenville	840.74	3	.10	840.84	1295.4
	Sydney	−852.37	3	.10	−852.27	443.2
	Amherst	−150.71	1	.03	−150.68	292.5
	Moncton	130.13	1	0	130.13	422.6
	Stephenville	0	—	—	0	1295.4
	Gander	112.57	—	—	112.57	1408.0

TABLE 1b.—RESULTS OBTAINED WITH WORDEN No. 44

Circuit	Station	ΔR_{sd} from preceding station	Adjustability	Adjustment	Adjusted ΔR_{sd} from preceding station	ΔR_{ld} converted to equivalent ΔR_{sd}	Total ΔR from preceding station	Total ΔR_{sd} from Ottawa
	Vancouver	0	—	—	0	0	0	2788.2
	Princeton	+3.8	—	—	3.8	−1439.3	−1435.5	1352.6
I	Princeton	0	—	—	0	0	0	1352.6
	Dog Creek	− 7.5	1	.2	−7.3	1111.8	1104.5	2457.1
	Prince George	−0.4	3	.5	0.1	2556.8	2556.9	5014.0
	Fort St. John	169.4	3	.5	169.9	1894.2	2064.1	7078.1
	Grande Prairie	−25.8	2	.3	−25.5	−782.4	−807.9	6270.2
	Edmonton	−48.3	2	.3	−48.0	−1242.9	−1290.9	4979.3
	Calgary	−37.6	3	.8	−36.8	−3080.1	−3116.9	1862.6
	Cranbrook	−37.3	4	.7	−36.6	−979.2	−1015.8	846.8
	Grand Forks	10.4	1	.2	10.6	521.8	532.4	1379.2
	Princeton	−26.7	2	.3	−26.4	0	−26.4	1352.6
II	Edmonton	0	—	—	0	0	0	4979.3
	Vermilion	78.1	1	−.1	78.0	0	78.0	5057.1
	Saskatoon	−396.5	1	−.1	−396.6	0	−396.6	4660.5
	Yorkton	400.1	3	−.2	399.9	−1180.5	−780.6	3879.9

TABLE 1b.—RESULTS OBTAINED WITH WORDEN NO. 44—*Con.*

Circuit	Station	ΔR_{sd} from preceding station	Adjustability	Adjustment	Adjusted ΔR_{sd} from preceding station	ΔR_{ld} converted to equivalent ΔR_{sd}	Total ΔR from preceding station	Total ΔR_{sd} from Ottawa
	Neepawa	−462.9	1	−.1	−463.0	0	−463.0	3416.9
	Winnipeg	−72.5	1	−.1	−72.6	0	−72.6	3344.3
	Portage La Prairie	162.7	1	.2	162.9	0	162.9	3507.2
	Brandon	−466.6	1	−.1	−466.7	0	−466.7	3040.5
	Regina	−16.8	3	−.2	−17.0	0	−17.0	3023.5
	Swift Current	562.1	2	−.1	562.0	−1375.8	−813.8	2209.7
	Medicine Hat	−75.0	1	−.1	−75.1	0	−75.1	2134.6
	Lethbridge	−360.8	2	−.1	−360.9	−588.4	−949.3	1185.3
	Calgary	416.0	3	−.2	415.8	261.5	677.3	1862.6
	Edmonton	37.6	3	−.8	36.8	3080.1	3116.9	4979.3
III	Winnipeg	0	—	—	0	0	0	3344.3
	Sioux Lookout	−255.7	1	−.3	−256.0	65.6	−190.4	3153.9
	Armstrong	425.0	2	−.5	424.5	0	424.5	3578.4
	Nakina	−5.3	1	−.3	−5.6	−262.3	−267.9	3310.5
	Kapuskasing	−147.2	1	−.3	−147.5	0	−147.5	3163.0
	Timmins	136.9	1	−.3	136.6	−1310.0	−1173.4	1989.6
	North Bay	209.1	1	−.3	208.8	−2152.9	−1944.1	45.3
	Sudbury	−510.9	1	.2	−510.7	977.5	466.8	512.3
	Sault Ste. Marie	77.5	3	−.7	76.8	0	76.8	589.1
	Marathon	15.2	2	−.5	14.7	1961.1	1975.8	2564.9
	Port Arthur	−10.3	2	−.5	−10.8	−785.7	−796.5	1768.4
	Graham	262.2	3	−.8	261.4	0	261.4	2029.8
	Kenora	85.3	1	−.3	85.0	982.3	1067.3	3097.1
	Portage la Prairie	−114.0	1	−.3	−114.3	524.4	410.1	3507.2
	Winnipeg	−162.7	1	−.2	−162.9	0	−162.9	3344.3
IV	Sudbury	0	—	—	0	0	0	512.3
	North Bay	510.9	1	−.2	510.7	−977.5	−466.8	45.3
	Ottawa	−44.6	1	−.5	−45.1	0	−45.1	0
	Montreal	7.5	1	−.7	6.8	195.6	202.4	202.4
	Trenton	43.3	1	−.5	42.8	−1306.7	−1263.9	−1061.5
	Toronto	−664.8	1	−.5	−665.3	0	−665.3	−1762.8
	Sudbury	−44.4	2	−1.0	45.4	2284.5	2239.1	512.3
V	Ottawa	0	—	—	0	0	0	0
	Quebec	−35.8	3	1.1	−34.7	1107.8	1073.1	1073.1
	Baie Comeau	−16.0	1	.4	−15.6	2092.9	2077.3	3150.4
	Chatham	−9.4	2	.8	−8.6	−1374.8	−1383.4	1767.0
	Moncton	57.3	2	.7	58.0	−913.5	−855.5	911.5
	Amherst	−281.6	1	.3	−281.3	0	−281.3	630.2
	Fredericton	−20.9	2	.8	−20.1	0	−20.1	610.1
	Megantic	112.9	2	.8	113.7	−1368.9	−1255.2	−645.1
	Montreal	195.0	1	.4	195.4	652.1	847.5	202.4
	Ottawa	−7.5	1	.7	−6.8	−195.6	−202.4	0
VI	Moncton	0	—	—	0	0	0	911.5
	Charlottetown	68.3	2	.2	68.5	0	68.5	980.0
	Stephenville	−78.8	2	.3	−78.5	1895.2	1816.7	2796.7
	Sydney	−9.6	2	.2	−9.4	−1830.8	−1840.2	956.5
	Amherst	−131.0	1	.1	−130.9	−195.4	−326.3	630.2
	Moncton	281.6	1	−.3	281.3	0	281.3	911.5
	Stephenville	0	—	—	0	0	0	2796.7
	Gander	243.3	—	—	243.3	0	243.3	3040.0

TABLE 1c.—RESULTS OBTAINED WITH WORDEN NO. 192

Circuit	Station	ΔR_{sd} from preceding station	Adjustability	Adjustment	Adjusted ΔR_{sd} from preceding station	ΔR_{ld} converted to equivalent ΔR_{sd}	Total ΔR from preceding station	Total ΔR_{sd} from Ottawa
	Vancouver	0	—	—	0	0	0	0
	Princeton	−2.6	—	—	−2.6	−1616.7	−1619.3	3156.2
I	Princeton	0	—	—	0	0	0	1536.9
	Dog Creek	−9.7	3	.4	−9.3	1257.6	1248.3	2785.2
	Prince George	337.5	1	.1	337.6	2564.9	2902.5	5687.7
	Fort St. John	−167.6	3	.4	−167.2	2513.5	2346.3	8034.0
	Grande Prairie	280.3	1	.1	280.4	−1196.3	−915.9	7118.1
	Edmonton	−559.0	1	.1	−558.9	−898.3	−1457.2	5660.9
	Calgary	−9.9	5	.5	−9.4	−3523.4	−3532.8	2128.1
	Cranbrook	−29.9	3	.4	−29.5	−1136.7	−1166.2	961.9
	Grand Forks	9.0	1	.1	9.1	598.0	607.1	1569.0
	Princeton	146.8	3	.4	147.2	−179.3	−32.1	1536.9
II	Edmonton	0	—	—	0	0	0	5660.9
	Vermilion	88.2	1	—	88.2	0	88.2	5749.1
	Saskatoon	−453.2	2	−.2	−453.4	0	−453.4	5295.7
	Yorkton	364.0	1	—	364.0	−1251.3	−887.3	4408.4
	Neepawa	−526.9	1	—	−526.9	0	−526.9	3881.5
	Winnipeg	−81.8	1	—	−81.8	0	−81.8	3799.7
	Portage la Prairie	183.7	1	.2	183.9	0	183.9	3983.7
	Brandon	−529.3	2	−.1	−529.4	0	−529.4	3454.3
	Regina	−13.7	2	−.1	−13.8	0	−13.8	3440.5
	Swift Current	513.3	2	−.1	513.2	−1433.6	−920.4	2520.1
	Medicine Hat	−82.4	3	−.1	−82.5	0	−82.5	2437.6
	Lethbridge	−363.4	3	−.1	−363.5	−719.1	−1082.6	1355.0
	Calgary	413.8	1	—	413.8	359.3	773.1	2128.1
	Edmonton	9.9	5	−.5	9.4	3523.4	3532.8	5660.9
III	Winnipeg	0	—	—	0	0	0	3799.7
	Sioux Lookout	−210.4	3	−.5	−210.9	0	−210.9	3588.8
	Armstrong	481.6	2	−.3	481.3	0	481.3	4070.1
	Nakina	51.6	2	−.4	51.2	−357.4	−306.2	3763.9
	Kapuskasing	−167.7	1	−.2	−167.9	0	−167.9	3596.1
	Timmins	48.6	2	−.4	48.2	−1376.1	−1327.9	2268.2
	North Bay	−3.5	2	−.4	−3.9	−2214.5	−2218.4	49.8
	Sudbury	−244.3	3	−.6	−244.9	778.6	533.7	583.5
	Sault Ste. Marie	88.4	2	−.3	88.1	0	88.1	671.6
	Marathon	26.4	2	−.4	26.0	2214.9	2240.9	2912.5
	Port Arthur	−3.2	3	−.5	−3.7	−898.8	−902.5	2010.0
	Graham	55.8	1	−.2	55.6	239.6	295.2	2305.2
	Kenora	16.1	2	−.3	15.8	1196.6	1212.4	3517.6
	Portage la Prairie	49.2	1	−.2	49.0	417.1	466.1	3983.7
	Winnipeg	−183.7	1	−.2	−183.9	0	−183.9	3799.7
IV	Sudbury	0	—	—	0	0	0	583.5
	North Bay	244.3	3	.6	244.9	−778.6	−533.7	49.8
	Ottawa	−49.7	2	−.1	−49.8	0	−49.8	0
	Montreal	230.4	1	.3	230.7	0	230.7	230.7
	Trenton	50.9	1	—	50.9	−1493.5	−1442.6	−1211.9
	Toronto	−398.2	3	−.2	−398.4	−357.2	−755.6	−1967.5
	Sudbury	−78.3	1	—	−78.3	2629.3	−2551.0	583.5
V	Ottawa	0	—	—	0	0	0	0
	Quebec	27.8	2	−.6	27.2	1197.4	1224.6	1224.6
	Baie Comeau	−87.8	1	−.3	−88.1	2452.8	2364.7	3589.3

TABLE 1c.—RESULTS OBTAINED WITH WORDEN No. 192—*Con.*

Circuit	Station	ΔR_{ed} from preceding station	Adjustability	Adjustment	Adjusted ΔR_{ed} from preceding station	ΔR_{ld} converted to equivalent ΔR_{ed}	Total ΔR from preceding station	Total ΔR_{ed} from Ottawa
	Chatham	42.9	3	−.9	42.0	−1615.4	−1573.4	2015.9
	Moncton	281.3	2	−.6	280.7	−1256.2	−975.5	1040.4
	Amherst	−320.4	3	−.3	−320.7	0	−320.7	719.7
	Fredericton	−22.8	2	−.6	−23.4	0	−23.4	696.3
	Megantic	67.2	3	−.9	66.3	−1496.8	−1430.5	−734.2
	Montreal	247.0	1	−.3	246.7	718.2	964.9	230.7
	Ottawa	−230.4	1	−.3	−230.7	0	−230.7	0
VI	Moncton	0	—	—	0	0	0	1040.4
	Charlottetown	77.5	3	−.4	77.1	0	77.1	1117.5
	Stephenville	−328.4	3	−.4	−328.8	2394.2	2065.4	3182.9
	Sydney	1.8	2	−.3	1.5	−2095.0	−2093.5	1089.4
	Amherst	−70.2	2	−.3	−70.5	−299.2	−369.7	719.7
	Moncton	320.4	3	.3	320.7	0	320.7	1040.4
	Stephenville	0	—	—	0	0	0	
	Gander	275.7	—	—	275.7	0	275.7	3458.6

TABLE 2a.—NETWORK ADJUSTMENT FOR NORTH AMERICAN No. 137

Circuit		I	II	III	IV	V	IV
Adjustability		24	19	23	12	16	9
Linkage adjustability			3	1	2	1	1
Closure error (divisions × 10^{-2})		−175	20	498	233	−69	−26
Circuit — Adjustment per unit adjustability (in divisions × 10^{-2})							
I	7	168	−21				
II	−1	3	−19	1			
III	−24		24	−552	48		
IV	−23			46	−276	23	
V	3				−3	48	−3
VI	3					−3	27
Residual closure error (divisions × 10^{-2})		−4	4	−7	2	−1	−2

TABLE 2b.—NETWORK ADJUSTMENT FOR WORDEN No. 44

Circuit		I	II	III	IV	V	VI
Adjustability		21	23	21	7	15	8
Linkage adjustability			3	1	1	1	1
Closure error (division × 10⁻¹)		−38	20	51	34	−60	−6
Circuit	Adjustment per unit adjustability (divisions × 10⁻¹)						
I	2	42	−6				
II	−1	3	−23	1			
III	−3		3	−63	3		
IV	−5			5	−35	5	
V	4				−4	60	−4
VI	1					−1	8
Residual closure error (divisions × 10⁻¹)		7	−6	−6	−2	4	−2

TABLE 2c.—NETWORK ADJUSTMENT FOR WORDEN No. 192

Circuit		I	II	III	IV	V	VI
Adjustability		21	25	27	11	18	13
Linkage adjustability			5	1	3	1	3
Closure error (divisions × 10⁻¹)		−25	10	49	−6	48	11
Circuit	Adjustment per unit adjustability (divisions × 10⁻¹)						
I	1	21	−5				
III	−2		2	−54	6		
V	−3				3	−54	9
VI	−2					6	−26
Residual closure error (divisions × 10⁻¹)		−4	7	−5	3	0	−6

procedure seemed justified as there is a setting error inherent in the use of the large dial of the order of one division.

The Calibration of the Gravimeters

As mentioned earlier, there are six places where the results could be compared with values of gravity measured by the Cambridge pendulum apparatus (Garland 1953a, 1955). The values obtained by Garland were referred to the airport stations by means of short-range gravity ties using automobile transportation. This information is summarized in the first column of Table 3. The next column shows these pendulum values expressed as gravity differences from the Ottawa airport station (A-24) and can be compared with the adjusted differences in instrument reading (ΔR), taken from Tables 1a, 1b, and 1c.

The scale constant of each instrument was computed by fitting the best least-square straight line to the values of Δg plotted against ΔR. Such a straight line is of the form $\Delta g_i = a + K\Delta R_i$ and the constants can be found (Tuttle & Satterley 1925) using the equations

$$K = \frac{\Sigma\Delta R\Sigma\Delta g - \eta\Sigma(\Delta R.\Delta g)}{(\Sigma\Delta R)^2 - \eta\Sigma\Delta R^2} \text{ mgals/div.}$$

$$\text{and } a = \frac{\Sigma\Delta R\Sigma(\Delta R.\Delta g) - \Sigma\Delta g\Sigma\Delta R^2}{(\Sigma\Delta R)^2 - \eta\Sigma\Delta R^2} \text{ mgals.}$$

The residuals, which are of the form $\rho = a + K\Delta R_i - \Delta g_i$, can be used to estimate the accuracy of the result since the standard deviation of a single station is

$$\delta_s = \pm\left[\frac{\Sigma(a + K\Delta R_i - \Delta g_i)^2}{\eta - 2}\right]^{\frac{1}{2}}$$

and the standard deviation of the scale constant (K) is

$$\delta_k = \delta_s\left[\frac{\eta}{(\Sigma\Delta R)^2 - \eta\Sigma\Delta R^2}\right]^{\frac{1}{2}}$$

In the above formula η denotes the number of points, six in the present case. The scale constants obtained for the three instruments are as follows:

$K_{137} = 0.239160 \pm 0.000055$ mgal/div. (p.e.)
$K_{44} = 0.110717 \pm 0.000065$ mgal/div. (p.e.)
$K_{192} = 0.097573 \pm 0.000050$ mgal/div. (p.e.)

The residuals from the equation for each instrument are listed in Table 4. At each station, although there is considerable spread, the residuals all have the same sign. Since it is highly improbable that three gravimeters would have similar nonlinear characteristics over this range of gravity at least part of the systematic discrepancy can be attributed to the pendulum values. From this it is apparent that the pendulum values are not sufficiently consistent with each other to be acceptable directly as control for the gravimeter network.

The Combination of the Observations

The adjusted ΔR's were multiplied by the appropriate scale constants to obtain the individual values of Δg listed in the first three columns of Table 5. From these values a mean was taken. Because of the variability of the individual determination of Δg a simple mean was not considered adequate and some simple rules for weighting the individual determinations and mean were established arbitrarily. If we denote the spread in any three determinations of a gravity difference

TABLE 3.—VALUES OF GRAVITY USED TO COMPUTE INSTRUMENTAL SCALE CONSTANTS

Station	g(Pend)	Δg from Ottawa A-24	ΔR_{137}	ΔR_{44}	$\Delta R_{7\ 192}$
	gals.	mgals.	divns.	divns.	divns.
Ottawa (Nat. Ref. Pier)	980.6220				
Ottawa A-24	980.6227	0	0	0	0
Lethbridge (Pendulum)	980.7612				
Lethbridge A-46	980.7555	132.8	554.1	1185.3	1355.0
Winnipeg (Pendulum)	980.9952				
Winnipeg A-13x	980.99395	371.25	1551.1	3344.3	3799.7
Edmonton (Pendulum)	981.1691				
Edmonton A-7	981.1745	551.8	2308.3	4979.3	5660.9
Grande Prairie (Pendulum)	981.3195				
Grande Prairie A-6	981.3173	694.6	2904.0	6270.2	7118.1
Fort St. John (Pendulum)	981.4077				
Fort St. John A-6	981.4073	784.6	3279.4	7078.1	8034.0

TABLE 4.—SUMMARY OF RESIDUALS

No.	Station	Δg (Pend)	$P_{137} = a + k\Delta R_{137} - \Delta g$	$P_{44} = a + k\Delta R_{44} - \Delta g$	$P_{192} = a + k\Delta R_{192} - \Delta g$
		mgals.	mgals.	mgals.	mgals.
A-24	Ottawa	0	.12	.73	.22
A-46	Lethbridge	132.8	−.16	−.84	−.37
A-13X	Winnipeg	371.25	−.17	−.25	−.28
A-7	Edmonton	551.8	.37	.23	.77
A-6	Grande Prairie	694.6	.04	.35	.16
A-5	Fort St. John	784.6	−.18	−.20	−.48

TABLE 5.—MEAN Δg'S AND ADJUSTMENT

Circuit	Station	Station Number	Δg_{137}	Δg_{44}	Δg_{193}	Unadjusted $\overline{\Delta g}$	Weight	Initial Adjustment	Modified Adjustability	Total Adjustment	Adjusted $\overline{\Delta g}$	g
	Vancouver	A-1	0	0	0	0	—	—	—	—	0	980.93141
	Princeton	A-2	—	−158.93	−158.00	−158.47	1	24	4	—	−158.47	980.77294
I	Princeton	A-2	0	0	0	0	—	—	—	—	0	980.77294
	Dog Creek	A-3	121.91	122.29	121.80	122.00	1	24	4	−0.11	121.89	.89483
	Prince George	A-4	283.05	283.09	283.21	283.12	8	3	0	0	283.12	981.17795
	Fort St. John	A-5	228.86	228.53	228.94	228.80	4	6	1	−0.02	228.78	.40673
	Grande Prairie	A-6	−89.76	−89.45	−89.37	−89.58	4	6	1	−0.02	−89.60	.31713
	Edmonton	A-7	−142.48	−142.92	−142.18	−142.52	2	12	2	−0.04	−142.56	981.17457
	Calgary	A-8	−344.32	−345.09	−344.71	−344.55	1	24	4	0.16	−344.39	980.83018
	Cranbrook	A-47	−113.43	−112.47	−113.79	−113.50	1	24	4	−0.10	−113.60	.71658
	Grand Forks	A-48	59.18	58.95	59.24	59.20	4	6	1	−0.02	59.18	.77576
	Princeton	A-2	−3.01	−2.92	−3.13	−2.80	4	6	1	−0.02	−2.82	.77294
II	Edmonton	A-7	0	0	0	0	—	—	—	—	0	981.17457
	Vermilion	A-9	8.69	8.64	8.61	8.65	12	2	0	0	8.65	.18322
	Saskatoon	A-10	−44.00	−43.91	−44.24	−43.98	6	4	0	0	−43.98	.13924
	Yorkton	A-11	−86.31	−86.43	−86.58	−86.41	4	6	1	−0.06	−86.47	.05277
	Neepawa	A-12	−51.39	−51.26	−51.41	−51.35	12	2	0	0	−51.35	.00142
	Winnipeg	A-13x	−8.09	−8.04	−7.98	−8.04	12	2	0	0	−8.04	980.99338
	Portage la Prairie	A-14	18.00	18.04	17.94	17.99	12	2	0	0	17.99	981.01137
	Brandon	A-42	−51.57	−51.67	−51.66	−51.63	12	2	0	0	−51.63	980.95974
	Regina	A-43	−1.33	−1.88	−1.35	−1.34	6	4	0	0	−1.34	.95840
	Swift Current	A-44	−89.84	−90.10	−89.81	−89.83	6	4	0	0	−89.83	.86857
	Medicine Hat	A-45	−8.15	−8.31	−8.05	−8.10	8	3	0	0	−8.10	.86047
	Lethbridge	A-46	−105.56	−105.10	−105.63	−105.50	4	6	1	−0.06	−105.56	.75491
	Calgary	A-8	75.22	74.99	75.43	75.33	4	6	1	−0.06	75.27	.83018
	Edmonton	A-7	344.32	345.09	344.71	344.55	1	24	4	−0.16	344.39	981.17457
III	Winnipeg	A-13x	0	0	0	0	—	—	—	—	0	980.99338
	Sioux Lookout	A-41	−21.10	−21.08	−20.58	−21.09	6	4	0	0	−21.09	.97229
	Armstrong	A-40	46.71	47.00	46.96	46.80	2	12	2	0.04	46.84	981.01913
	Nakina	A-39	−29.77	−29.66	−29.87	−29.77	8	3	0	0	−29.77	980.98936
	Kapuskasing	A-38	−16.30	−16.33	−16.38	−16.34	12	2	0	0	−16.34	.97302
	Timmins	A-37	−129.35	−129.92	−129.57	−129.66	1	24	4	0.06	−129.60	.84342
	North Bay	A-36	−216.13	−215.24	−216.46	−215.84	1	24	4	0.06	−215.78	.62764
	Sudbury	A-20	52.12	51.68	52.07	51.96	2	12	2	0.10	52.06	.67970
	Sault Ste. Marie	A-19	8.61	8.50	8.60	8.57	12	2	0	0	8.57	.68827
	Marathon	A-18	219.02	218.75	218.65	218.75	6	4	0	0	218.75	.90702
	Port Arthur	A-17	−88.30	−88.19	−88.06	−88.18	8	3	0	0	−88.18	.81884
	Graham	A-16	28.82	28.94	28.80	28.85	12	2	0	0	28.85	.84769
	Kenora	A-15	118.20	118.17	118.30	118.22	12	2	0	0	118.22	.96591
	Portage la Prairie	A-14	45.48	45.41	45.48	45.46	12	2	0	0	45.46	981.01137
	Winnipeg	A-13x	−18.00	−18.04	−17.94	−17.99	12	2	0	0	−17.99	980.99338

TABLE 5.—MEAN Δg's AND ADJUSTMENT—*Con.*

Circuit	Station	Station Number	Δg_{137}	Δg_{44}	Δg_{192}	Unadjusted $\overline{\Delta g}$	Weight	Initial Adjustment	Modified Adjustability	Total Adjustment	Adjusted $\overline{\Delta g}$	g
IV	North Bay	A-36	0	0	0	0	—	—	—	—	0	980.62764
	Ottawa	A-24	−5.01	−4.99	−4.86	−4.95	12	2	0	−0.02	−4.97	980.62267
	Montreal	A-23	22.40	22.41	22.51	22.44	12	2	0	−0.02	22.42	.64509
	Trenton	A-22	−140.37	−139.94	−140.76	−140.36	2	12	2	−0.05	−140.41	.50468
	Toronto	A-21	−73.57	−73.66	−73.73	−73.65	8	3	0	−0.03	−73.68	.43100
	Sudbury	A-20	248.67	247.91	248.91	248.75	2	12	2	−0.05	248.70	.67970
	North Bay	A-36	−52.12	−51.68	−52.07	−51.96	2	12	2	−0.10	−52.06	.62764
V	Ottawa	A-24	0	0	0	0	—	—	—	—	0	980.62267
	Quebec	A-25	119.12	118.81	119.49	119.21	2	12	2	−0.02	119.19	.74186
	Baie Comeau	A-26	230.18	229.99	230.73	230.25	1	24	4	−0.07	230.18	.97204
	Chatham	A-27	−153.27	−153.17	−153.52	−153.28	4	6	1	−0.01	−153.29	.81875
	Moncton	A-28	−94.96	−94.72	−95.18	−94.96	4	6	1	−0.01	−94.97	.72378
	Amherst	A-29	−31.12	−31.14	−31.29	−31.18	8	3	0	0	−31.18	.69260
	Fredericton	A-34	−2.25	−2.23	−2.28	−2.25	12	2	0	0	−2.25	.69035
	Megantic	A-35	−139.10	−138.97	−139.58	−139.10	1	24	4	−0.07	−139.17	.55118
	Montreal	A-23	93.79	93.83	94.15	93.92	4	6	1	−0.01	93.91	.64509
	Ottawa	A-24	−22.40	−22.41	−22.51	−22.44	12	2	0	0.02	−22.42	.62267
VI	Moncton	A-28	0	0	0	0	—	—	—	—	—	980.72378
	Charlottetown	A-30	7.65	7.58	7.52	7.58	12	2	0	0	7.58	.73136
	Stephenville	A-31	201.10	201.14	201.53	201.20	4	6	1	0.02	201.22	.93258
	Sydney	A-33	−203.83	−203.74	−204.27	−203.95	2	12	2	0.05	−203.90	.72868
	Amherst	A-29	−36.04	−36.13	−36.07	−36.08	12	2	0	0	−36.08	.69260
	Moncton	A-28	31.12	31.14	31.29	31.18	8	3	0	0	31.18	.72378
	Stephenville	A-31	0	0	0	0	—	—	—	—	0	980.93258
	Gander	A-32	26.92	26.94	26.90	26.92	12	2	0	0	26.92	.95950

ence (Δg) by $\sigma(\Delta g)$, the value of the mean as $\overline{\Delta g}$, and the weight assigned to the mean as w, then the rules can be summarized.

1. If $\sigma(\Delta g) \nless 0.15$ mgal, then $\overline{\Delta g}$ is an arithmetic mean and $w = 12$.
2. If $0.15 < \sigma(\Delta g) < 0.25$, then $\overline{\Delta g}$ is an arithmetic mean and $w = 8$.
3. If $0.25 < \sigma(\Delta g) < 0.40$, then $\overline{\Delta g}$ is a weighted mean (from an inspection of the drift curves) and $w = 4$. In the computation of $\overline{\Delta g}$ less weight is given to the Worden values of $\Delta g > 100$ milligals. If σ (Δg) appears to be largely due to *one* of the Worden instruments the assigned weight is $w = 6$.
4. If σ (Δg) > 0.4 milligal but 2 of the 3 instruments appear reliable then $w = 2$ is assigned to the weighted mean.
5. If σ (Δg) > 0.4 milligal and the processes used to assign a mean are more intuitive, then the assigned weight is $w = 1$.

Using these rules the mean unadjusted Δg's listed in the fourth column were calculated. The next column lists the weights assigned to these values.

Before these results can be used to compute values of gravity the network must be readjusted in the manner described earlier in this report. The values of "unadjusted Δg" were first given an "initial adjustability" proportional to the reciprocal of the weight. These values are listed for each leg in Table 5; the total adjustability of each circuit and the linkage adjustabilities are given in the first two lines of Table 6.

The large values of these adjustabilities raised the problem of how they were to be used in adjusting the closure errors listed in the next line of Table 6. Since the uncertainties in the values of Δg are of the order of one or two tenths of a milligal it was considered unrealistic to carry out the adjustment beyond the hundredth of a milligal. With the initial adjustabilities it was possible to alter only one circuit (circuit IV) in order to reduce the closure errors.

The next step was the assignment of modified adjustabilities (A_m). The rules used here were:

if $W \geq 6, A_m = 0$
$W = 4, A_m = 1$
$W = 2, A_m = 2$
$W = 1, A_m = 4$

TABLE 6.—NETWORK ADJUSTMENT FOR MEAN Δg's

	Circuit	I		II		III		IV		V		VI
	Initial adjustability	111		67		98		43		85		25
	Initial linkage adjustability		24		2		12		2		3	
	Unadjusted closure error (mgls × 10^{-2})	17		34		−26		27		17		−7
Circuit	Adjustment per unit adjustability (mgls × 10^{-2})											
IV	−1					12		−43		2		
	Intermediate closure error (mgls × 10^{-2})	17		34		−14		−16		19		−7
	Modified adjustability	18		7		12		6		13		3
	Modified linkage adjustability		4		0		2		0		0	
Circuit	Adjustment per unit modified adjustability (mgls × 10^{-2})											
I	−2	−36		8								
II	−6	24		−42								
III	2					24		−4				
IV	3					−6		18				
V	−1									−13		
VI	2											6
	Residual closure error (mgls × 10^{-2})	5		0		4		−2		6		−1

Using these values it was possible to carry out the network adjustment until the residual closure error for any circuit was only a few hundredths of a milligal. These residual closure errors were arbitrarily distributed as follows:

Circuit I: −0.03 mgal to the $\overline{\Delta g}$ for Princeton-Dog Creek.
−0.02 mgal to the $\overline{\Delta g}$ for Calgary-Cranbrook.

Circuit III: −0.02 mgal to the $\overline{\Delta g}$ for North Bay-Kapuskasing.
−0.02 mgal to the $\overline{\Delta g}$ for Kapuskasing-Timmins.

Circuit IV: +0.01 mgal to the $\overline{\Delta g}$ for Montreal-Trenton.
+0.01 mgal to the $\overline{\Delta g}$ for Toronto-Sudbury.

Circuit V: −0.03 mgal to the $\overline{\Delta g}$ for Quebec-Baie Comeau.
−0.03 mgal to the $\overline{\Delta g}$ for Fredericton-Megantic.

Circuit VI: +0.01 mgal to the $\overline{\Delta g}$ for Stephenville-Sydney.

As before, the convention of a plus sign for a clockwise adjustment is maintained. The above adjustments together with those derived in Table 6, are listed for each leg in Table 5, followed by the adjusted values of $\overline{\Delta g}$. From these values of $\overline{\Delta g}$, the values of gravity at each site were computed, starting with an adopted value g = 980.62267 for A-24, the Ottawa airport station. These values are listed to the nearest hundredth of a milligal in the last column of Table 6.

The Accuracy of the Measurements

It was originally hoped that the present base network might serve as a standard reference for future regional surveys. While this purpose has not been achieved—since there are uncertainties of several tenths of a milligal in some of the connections—the encouraging feature of the results is that nowhere is there a discrepancy as great as 1 milligal at points where comparison can be made with previously adopted values of gravity.

When discussing errors in the values of gravity adopted for base stations it must be borne in mind that there are three sources of error:

(i) error in the value of gravity adopted as a reference.

(ii) errors in the adopted scale constants of the instrument(s) used to make the connections.

(iii) errors in the reading differences (ΔR's) adopted for the measurements. In other words,

$$g_s = g_o + \Sigma K \Delta R$$

where g_s = value of gravity assigned to a station,
g_o = adopted value at a base station,
ΔR = difference in gravimeter reading (corrected for drift) between two intermediate stations,
k = instrumental scale constant assigned to any particular ΔR.

For example, in comparing the present value at Charlottetown with the previously published value (Garland, 1953b) it must be realized that the agreement to 0.2 milligal is largely fortuitous. The 1953 value at Charlottetown is based upon an adopted value at Amherst 0.5 milligal greater than the 1955 value. On the other hand, comparison with previously adopted values in Western Canada (Garland and Tanner 1957) shows an agreement to within several tenths of a milligal, since both sets of data are based upon the values of gravity given by the Cambridge pendulums.

A rigorous over all adjustment of the values of gravity in Canada, including previous work, was not considered feasible. Because of factors such as those discussed in the previous paragraph, such an adjustment, however adequate mathematically, would still rest upon a weighting procedure which would be largely subjective.

Since three instruments were used for the 1955 survey it should be possible to assess the performance of each instrument by intercomparison of the results. The theory of this is straightforward. The North American instrument No. 137 is denoted by the subscript 1, the Worden No. 44 by the subscript 2, and the Worden No. 192 by the subscript 3.

For each leg of the network the adjusted values of Δg for the three instruments (Table 5) can be written as Δg_1, Δg_2, Δg_3. The residuals between any two instruments are due to errors in each instrument, and so the residuals, for any leg, are computed as:

$$\rho_{23} = |\Delta g_2 - \Delta g_3|$$
$$\rho_{31} = |\Delta g_3 - \Delta g_1|$$
$$\rho_{12} = |\Delta g_1 - \Delta g_2|$$

The standard deviation of any instrument for a single leg can be calculated from the sum of the squares of these residuals. If the standard deviations are denoted by σ_1, σ_2 and σ_3, then we can write $\frac{1}{(\eta-1)} \Sigma \rho^2_{23} = \sigma_2^2 + \sigma_3^2$ etc. and therefore

$$\sigma_1^2 = \frac{1}{2(\eta - 1)} (\Sigma \rho_{31}^2 + \Sigma \rho_{12}^2 - \Sigma \rho_{23}^2)$$

$$\sigma_2^2 = \frac{1}{2(\eta - 1)} (\Sigma \rho_{23}^2 + \Sigma \rho_{12}^2 - \Sigma \rho_{31}^2)$$

$$\sigma_3^2 = \frac{1}{2(\eta - 1)} (\Sigma \rho_{23}^2 + \Sigma \rho_{31}^2 - \Sigma \rho_{12}^2)$$

TABLE 7.

From	To	ρ_{23} mgls $\times 10^{-2}$	ρ_{31} mgls $\times 10^{-2}$	ρ_{12} mgls $\times 10^{-2}$	$\lvert\overline{\Delta g}\rvert$ mgls
Princeton	Dog Creek	49	11	38	122
Dog Creek	Prince George	12	16	4	283
Prince George	Fort St. John	41	8	33	229
Fort St. John	Grande Prairie	8	39	31	90
Grande Prairie	Edmonton	74	30	44	143
Edmonton	Calgary	38	39	77	344
Edmonton	Vermilion	3	8	5	9
Vermilion	Saskatoon	33	24	9	44
Saskatoon	Yorkton	15	27	12	86
Yorkton	Neepawa	15	2	13	51
Neepawa	Winnipeg	6	11	5	8
Winnipeg	Portage la Prairie	10	6	4	18
Portage la Prairie	Kenora	7	0	7	45
Kenora	Graham	13	10	3	118
Graham	Port Arthur	14	2	12	29
Port Arthur	Marathon	13	24	11	88
Marathon	Sault Ste. Marie	10	37	27	219
Sault Ste. Marie	Sudbury	10	1	11	9
Sudbury	Toronto	100	24	76	249
Toronto	Trenton	7	16	9	74
Trenton	Montreal	82	39	43	140
Montreal	Ottawa	10	11	1	22
Ottawa	Quebec	68	37	31	119
Quebec	Baie Comeau	74	55	19	230
Baie Comeau	Chatham	35	25	10	153
Chatham	Moncton	46	22	24	95
Moncton	Amherst	15	17	2	31
Moncton	Charlottetown	6	13	7	8
Charlottetown	Stephenville	39	43	4	201
Stephenville	Gander	4	2	2	27
Stephenville	Sydney	53	44	9	204
Sydney	Amherst	6	3	9	36
Amherst	Fredericton	5	3	2	2
Fredericton	Megantic	61	48	13	139
Megantic	Montreal	32	36	4	94
Ottawa	North Bay	13	15	2	5
North Bay	Sudbury	39	5	44	52
North Bay	Timmins	122	33	89	216
Timmins	Kapuskasing	35	22	57	130
Kapuskasing	Nakina	5	8	3	16
Nakina	Armstrong	21	10	11	30
Armstrong	Sioux Lookout	4	25	29	47
Sioux Lookout	Winnipeg	50	52	2	21
Portage la Prairie	Brandon	1	9	10	52
Brandon	Regina	53	2	55	1
Regina	Swift Current	29	3	26	90
Swift Current	Medicine Hat	26	10	16	8
Medicine Hat	Lethbridge	53	7	46	106
Lethbridge	Calgary	44	21	23	75
Calgary	Cranbrook	132	36	96	114
Cranbrook	Grand Forks	29	6	23	59
Grand Forks	Princeton	21	12	9	3

From these formulae it is obvious that to avoid imaginary values of σ, any two of the values of $\Sigma\rho^2$ must together be greater than the third. The only significance that can be attached to imaginary values of σ is that non-random errors have become dominant and therefore the analysis is inapplicable.

The residuals necessary for this analysis are listed in Table 7. Also included in this table for easy reference are the adjusted values of gravity difference. They are listed under the column headed $|\Delta g|$ without regard to sign and rounded off to the nearest milligal. The computations.are summarized in Table 8, where it can be seen that ten different arrangements of the data have been made.

In example 1, only those values of $|\overline{\Delta g}|$ less than or equal to 30 milligals have been considered. The standard deviation which these values give for the North American instrument is only 0.016 milligal, certainly a fortuitously low figure. The two Worden instruments have apparent standard deviations which are ten times greater than this. Considering also examples 2, 3, 6, and 7 which all treat data where $|\overline{\Delta g}| < 100$ milligals the apparent standard deviation of North American No. 137 is about half that of either of the Worden instruments. This result could not be anticipated from the closure errors around the circuits, which are listed in Table 2, and summarized in Figure 2.

When only those values where $|\overline{\Delta g}| > 100$ milligals (examples 4 and 5) or combinations of the data (Examples 8 and 9), are considered the analysis yields imaginary values of σ_1, and the implication is that large non-random errors occur in some of the larger Δg's measured with the Worden instruments. Some confirmation of this is given by example 10, an analysis which includes only those values of Δg measured with the Worden instruments without changing the settings of the large dials. It is in this case that the lowest values of σ_2 and σ_3 are found. Bearing in mind that for each reading the large dial of each instrument had to be set, even when there was no change needed in that setting, example 10 indicates that the Worden instruments with only one dial have about the same accuracy as the North American instrument, at least for this type of work when aircraft transportation is used. The standard deviations of Worden No. 44 are about the same as those of Worden No. 192, despite the fact that the former instrument was continuously temperature controlled. However, this does not mean that an instrument using a thermostatted container is not improved, as there was some evidence that No. 44 was generally inferior in performance to No. 192. What it does mean, is that the technique of temperature control of a Worden meter needs careful review if the extra weight is to be justified.

The obvious superiority of the North American instrument in the present work raises the question as to whether values of gravity should be computed using this instrument alone. This has not been done because no justifiable rejection criterion can be applied.

In order to estimate the standard deviations of the weighted mean values of Δg, the last three columns of Table 8 are used, particularly Examples 7 and 9. From these, the standard deviation of a single value of $\overline{\Delta g}$ is estimated at 0.1 milligal. Values of gravity for stations remote from Ottawa involve the summation of many individual $\overline{\Delta g}$'s. Hence the indicated standard deviation of the values of gravity ranges from 0.1 milligal for stations adjacent to Ottawa to 0.25 milligal for Gander and 0.4 for Princeton. Vancouver is a special case, having an even greater uncertainty, since the connection depends upon the Worden instruments alone, with a resulting uncertainty for $\overline{\Delta g}$ of 0.5 milligal (*see* Table 5).

It is quite likely that the standard deviations given in the previous paragraph are too low, since non-random errors are not accounted for. For example, the large and inexplicable closure error of 1.2 milligals found with North American No. 137 in Circuit III (*see* Figure 2), indicates that at least once during the survey the scale constant of this instrument changed.

The final standard deviations assigned to the values of gravity are estimated as ranging from 0.2 milligal for stations near Ottawa to 0.5 milligal for stations further from Ottawa. These figures appear to be in satisfactory agreement with previously adopted gravity values.

Descriptions of Stations

The values of gravity listed in the last column of Table 5 all refer to airport stations used in the 1955 survey. To enable future observers to recover these stations, sketches are given in Figure 3. The following supplementary notes may prove useful.

Vancouver, B.C.—The 1955 station A-1 is near a previous Dominion Observatory base established by J. A. Robinson (at bronze marker in Figure 3). A-1 was chosen as having a more sheltered location, but observers using a car will find the bronze marker is 0.06 milligal greater than that at A-1.

Princeton, B.C.—The gravity station at the airport has a value of gravity 6.02 milligals greater than that at the C.P.R. station (Garland and Tanner 1957).

Dog Creek, B.C.—This station is not connected to other Dominion Observatory stations. For those wishing to compute the Bouguer anomaly, the best estimate of elevation is 3370′ ± 10′.

TABLE 8.—ESTIMATION OF STANDARD DEVIATION OF A SINGLE CONNECTION

Example No.	Range of $\overline{\Delta g}$	η	$\Sigma\rho^2_{23}$	$\Sigma\rho^2_{31}$	$\Sigma\rho^2_{12}$	$\Sigma\rho^2_{23}/\eta\text{-}1$	$\Sigma\rho^2_{31}/\eta\text{-}1$	$\Sigma\rho^2_{12}/\eta\text{-}1$	σ_1	σ_2	σ_3
	mgals		mgals$^2\times10^{-4}$	mgals$^2\times10^{-4}$	mgals$^2\times10^{-4}$	mgals$^2\times10^{-4}$	mgals$^2\times10^{-4}$	mgals$^2\times10^{-4}$	mgals$\times10^{-2}$	mgals$\times10^{-2}$	mgals$\times10^{-2}$
1	$\lvert\overline{\Delta g}\rvert \leq 30$	16	7,679	3,870	3,889	512	258	259	1.6	16.0	16.0
2	$30 < \lvert\overline{\Delta g}\rvert \leq 60$	9	4,003	1,645	3,790	500	206	474	9.5	19.6	10.8
3	$60 < \lvert\overline{\Delta g}\rvert \leq 100$	8	6,424	5,312	3,104	918	759	443	11.9	17.3	24.8
4	$100 < \lvert\overline{\Delta g}\rvert \leq 150$	9	44,573	8,144	20,949	5,572	1,018	2,619	$31.1\sqrt{-1}$	59.9	44.6
5	$\lvert\overline{\Delta g}\rvert > 150$	10	39,284	12,310	22,018	4,365	1,368	2,446	$16.6\sqrt{-1}$	52.2	40.6
6	$\lvert\overline{\Delta g}\rvert < 60$	25	11,682	5,515	7,679	487	230	320	5.6	17.0	14.1
7	$\lvert\overline{\Delta g}\rvert < 100$	33	18,106	10,827	10,783	566	338.5	337	7.4	16.8	16.8
8	$\lvert\overline{\Delta g}\rvert < 150$	42	62,679	18,971	31,732	1,529	463	774	$12.1\sqrt{-1}$	30.3	24.7
9	All $\overline{\Delta g}$'s	52	101,963	31,281	53,750	1,999	613	1,054	$12.9\sqrt{-1}$	34.9	27.9
10	All Small Dial $\overline{\Delta g}$'s	16	2,848	2,489	1,709	190	166	114	6.7	8.3	11.0

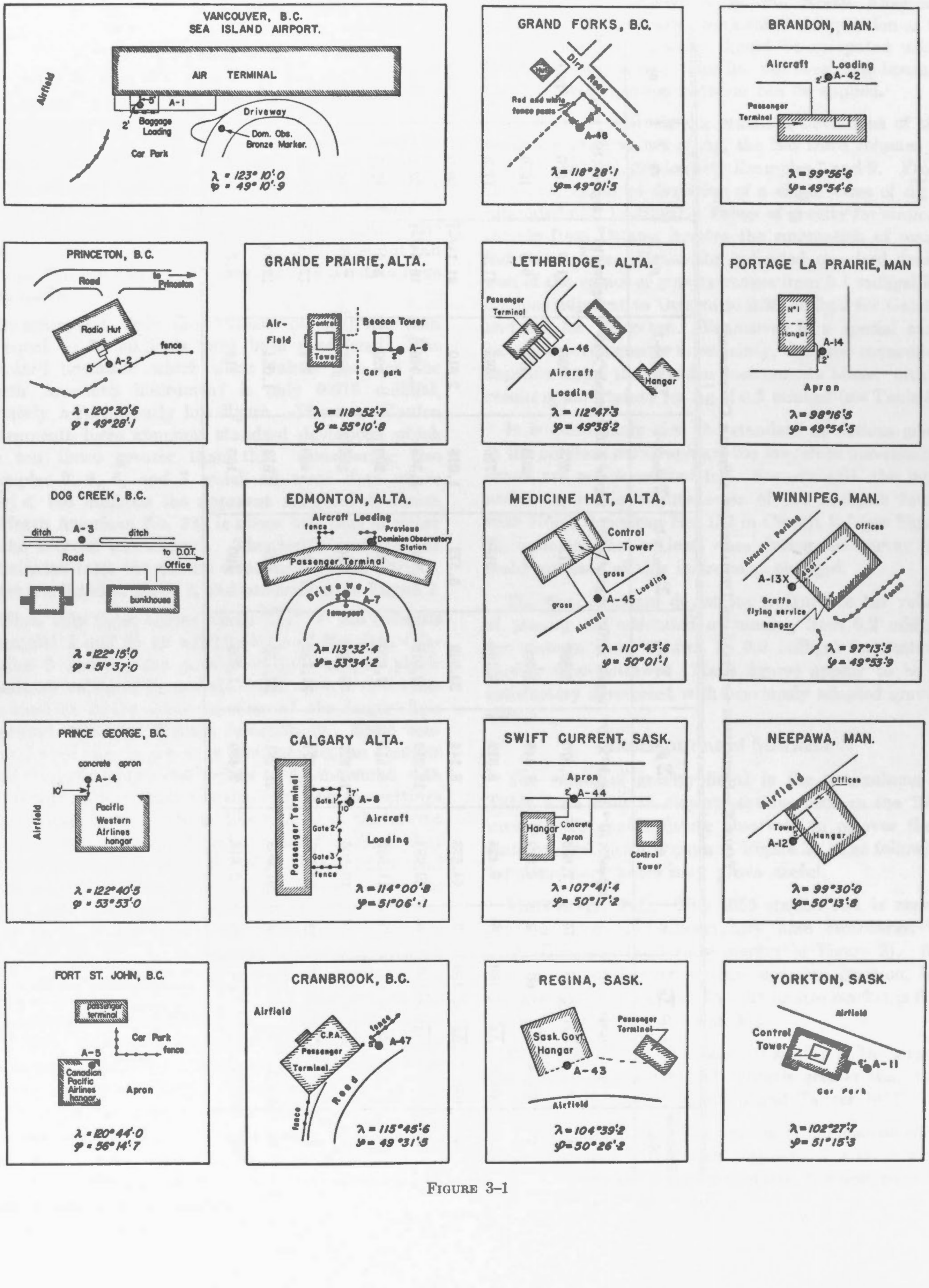
VANCOUVER, B.C.
SEA ISLAND AIRPORT.
AIR TERMINAL
Airfield
A-1
Baggage Loading
Driveway
Dom. Obs. Bronze Marker.
Car Park
λ = 123° 10'.0
φ = 49° 10'.9
GRAND FORKS, B.C.
Dirt Road
Red and white fence posts
A-48
λ = 118°28'.1
φ = 49°01'.5
BRANDON, MAN.
Aircraft Loading
A-42
Passenger Terminal
λ = 99°56'.6
φ = 49°54'.6
PRINCETON, B.C.
Road
to Princeton
Radio Hut
fence
A-2
λ = 120°30'.6
φ = 49°28'.1
GRANDE PRAIRIE, ALTA.
Air-Field
Control Tower
Beacon Tower
A-6
Car park
λ = 118°52'.7
φ = 55°10'.8
LETHBRIDGE, ALTA.
Passenger Terminal
A-46
Aircraft Loading
Hangar
λ = 112°47'.3
φ = 49°38'.2
PORTAGE LA PRAIRIE, MAN
N°1 Hangar
A-14
Apron
λ = 98°16'.5
φ = 49°54'.5
DOG CREEK, B.C.
ditch
A-3
ditch
Road
to D.O.T. Office
bunkhouse
λ = 122°15'.0
φ = 51°37'.0
EDMONTON, ALTA.
Aircraft Loading
fence
Previous Dominion Observatory Station
Passenger Terminal
Driveway
A-7
lamppost
λ = 113°32'.4
φ = 53°34'.2
MEDICINE HAT, ALTA.
Control Tower
grass
Loading
A-45
grass
Aircraft
λ = 110°43'.6
φ = 50°01'.1
WINNIPEG, MAN.
Aircraft Parking
Offices
A-13X
Graffo flying service hangar
fence
λ = 97°13'.5
φ = 49°53'.9
PRINCE GEORGE, B.C.
concrete apron
A-4
Airfield
Pacific Western Airlines hangar
λ = 122°40'.5
φ = 53°53'.0
CALGARY ALTA.
Passenger Terminal
Gate 1
Gate 2
Gate 3
fence
A-8
Aircraft Loading
λ = 114°00'.8
φ = 51°06'.1
SWIFT CURRENT, SASK.
Apron
A-44
Hangar
Concrete Apron
Control Tower
λ = 107°41'.4
φ = 50°17'.2
NEEPAWA, MAN.
Airfield
Offices
Tower
A-12
Hangar
λ = 99°30'.0
φ = 50°13'.8
FORT ST. JOHN, B.C.
passenger terminal
Car Park
fence
A-5
Canadian Pacific Airlines hangar
Apron
λ = 120°44'.0
φ = 56°14'.7
CRANBROOK, B.C.
Airfield
C.P.A. Passenger Terminal
fence
A-47
Road
fence
λ = 115°45'.6
φ = 49°31'.5
REGINA, SASK.
Sask. Gov. Hangar
Passenger Terminal
A-43
Airfield
λ = 104°39'.2
φ = 50°26'.2
YORKTON, SASK.
Airfield
Control Tower
A-11
Car Park
λ = 102°27'.7
φ = 51°15'.3

FIGURE 3-1

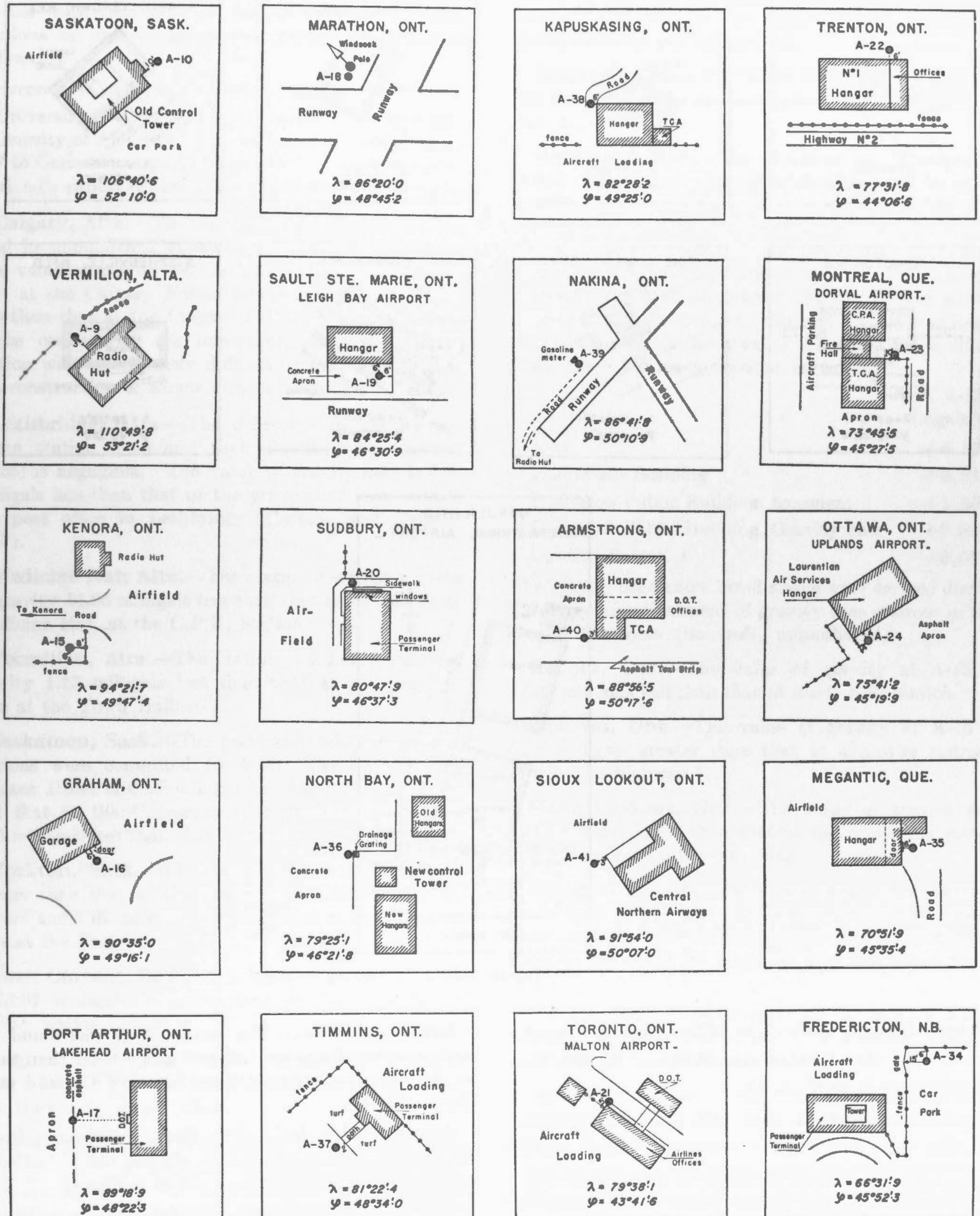
SASKATOON, SASK.
Airfield
A-10
Old Control Tower
Car Park
λ = 106°40'6
φ = 52°10'0
MARATHON, ONT.
Windsock Pole
A-18
Runway
Runway
λ = 86°20'0
φ = 48°45'2
KAPUSKASING, ONT.
Road
A-38
Hangar
TCA
fence
Aircraft Loading
λ = 82°28'2
φ = 49°25'0
TRENTON, ONT.
A-22
N°1 Hangar
Offices
fence
Highway N°2
λ = 77°31'8
φ = 44°06'6
VERMILION, ALTA.
fence
A-9
Radio Hut
λ = 110°49'8
φ = 53°21'2
SAULT STE. MARIE, ONT.
LEIGH BAY AIRPORT
Hangar
Concrete Apron
A-19
Runway
λ = 84°25'4
φ = 46°30'9
NAKINA, ONT.
Gasoline meter
A-39
Road
Runway
Runway
To Radio Hut
λ = 86°41'8
φ = 50°10'9
MONTREAL, QUE.
DORVAL AIRPORT.
Aircraft Parking
C.P.A. Hangar
Fire Hall
A-23
T.C.A. Hangar
Road
Apron
λ = 73°45'5
φ = 45°27'5
KENORA, ONT.
Radio Hut
Airfield
To Kenora
Road
A-15
fence
λ = 94°21'7
φ = 49°47'4
SUDBURY, ONT.
A-20
Sidewalk
windows
Air-Field
Passenger Terminal
λ = 80°47'9
φ = 46°37'3
ARMSTRONG, ONT.
Concrete Apron
Hangar
D.O.T. Offices
A-40
TCA
Asphalt Taxi Strip
λ = 88°56'5
φ = 50°17'6
OTTAWA, ONT.
UPLANDS AIRPORT.
Laurentian Air Services Hangar
A-24
Asphalt Apron
λ = 75°41'2
φ = 45°19'9
GRAHAM, ONT.
Garage
Airfield
door
A-16
λ = 90°35'0
φ = 49°16'1
NORTH BAY, ONT.
Old Hangars
Drainage Grating
A-36
Concrete Apron
New control Tower
New Hangars
λ = 79°25'1
φ = 46°21'8
SIOUX LOOKOUT, ONT.
Airfield
A-41
Central Northern Airways
λ = 91°54'0
φ = 50°07'0
MEGANTIC, QUE.
Airfield
Hangar
door
A-35
Road
λ = 70°51'9
φ = 45°35'4
PORT ARTHUR, ONT.
LAKEHEAD AIRPORT
concrete asphalt
Apron
A-17
door
Passenger Terminal
λ = 89°18'9
φ = 48°22'3
TIMMINS, ONT.
fence
Aircraft Loading
turf
Passenger Terminal
path
A-37
turf
λ = 81°22'4
φ = 48°34'0
TORONTO, ONT.
MALTON AIRPORT.
A-21
D.O.T.
Aircraft Loading
Airlines Offices
λ = 79°38'1
φ = 43°41'6
FREDERICTON, N.B.
gate
A-34
Aircraft Loading
Tower
fence
Car Park
Passenger Terminal
λ = 66°31'9
φ = 45°52'3

FIGURE 3–2

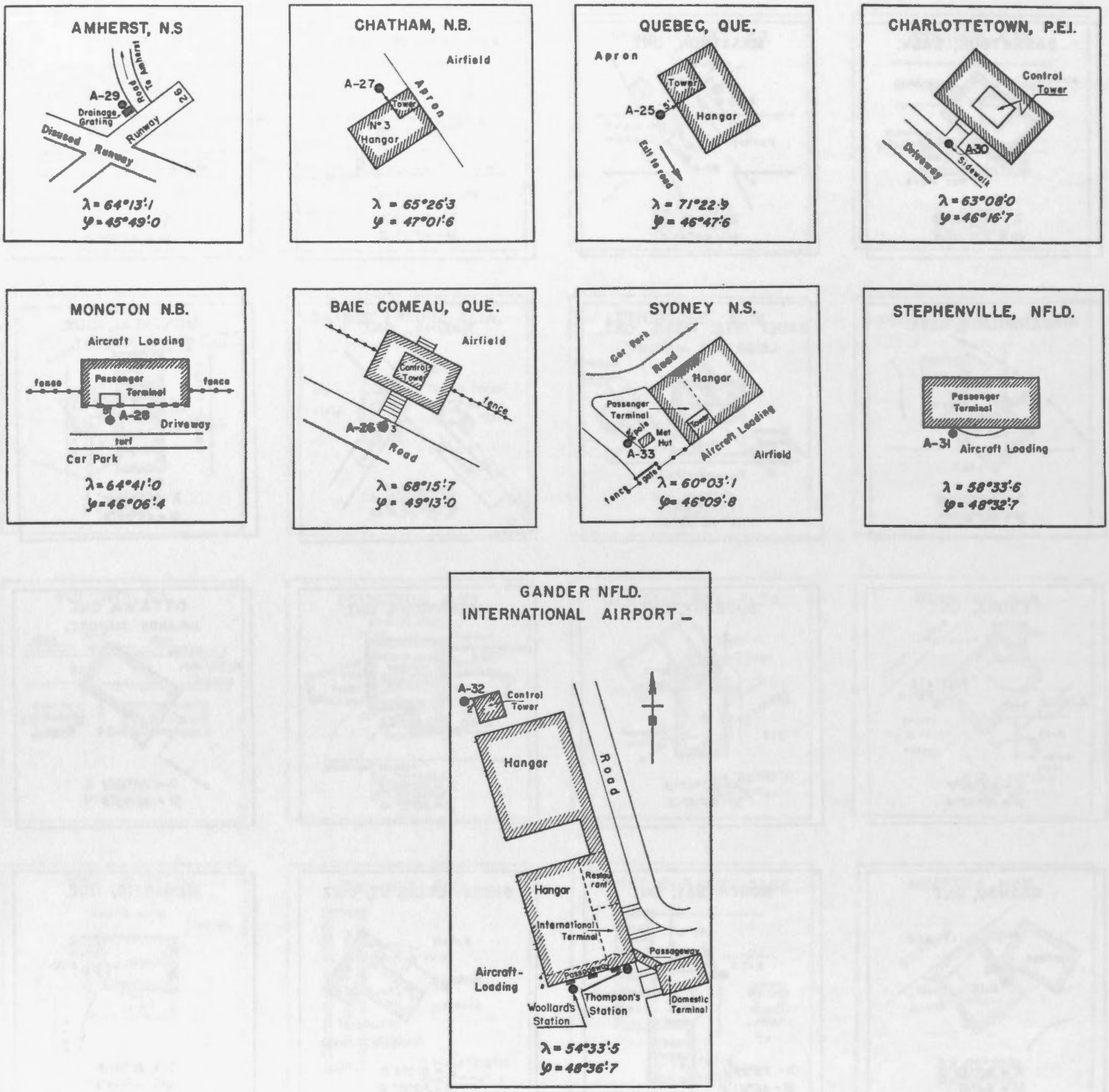

FIGURE 3–3

Prince George, B.C.—The 1955 station A-4 is unconnected to other Observatory stations. Its approximate elevation is 2230′ ± 15′.

Fort St. John, B.C.—The 1955 station is identical with the one described by Garland (1955). Three independent determinations of the difference in gravity between this station and the pendulum site yield a mean of 0.44 ± 0.02 milligal, the pendulum site having the larger value of gravity.

Cranbrook, B.C.—The station A-47 was found to have a value of gravity 1.20 milligals greater than that at the Cranbrook Post Office station of Garland and Tanner (1957).

Grand Forks, B.C.—The Gravity difference from the station A-48 to the C.P.R. station site of Garland and Tanner was measured as +3.98 milligals.

Grande Prairie, Alta.—The station A-6 is identical with that of Garland (1955), and has a value of gravity 2.22 milligals less than that at his pendulum site.

Edmonton, Alta.—The station A-7 is more useful for car work than that of Garland (1955). The connections to various Edmonton gravity bases are as follows:

University of Alberta pendulum site to University of Alberta gravity base:	−0.40 mgal.
University of Alberta gravity base to A-7:	−5.82 mgals.
A-7 to Garland's airport station:	−0.10 mgal.
Garland's airport station to pendulum site:	−5.32 mgals.

Calgary, Alta.—The station A-8 is identical to one used in unpublished observations by J. A. Robinson. The value of gravity here is 0.13 milligal greater than that at the Calgary Public Library, and 0.72 milligal less than that at the Calgary C.P.R. Telegraph Office. These connections are important, since the airport station will be extremely difficult to relocate following the construction of a new airport building.

Lethbridge, Alta.—The difference in gravity between station A-46 and that described by Garland (1955) is negligible. The value of gravity here is 4.99 milligals less than that at the gravimeter base outside the post office in Lethbridge (Garland and Tanner, 1957).

Medicine Hat, Alta.—The station A-45 has a value of gravity 14.66 milligals less than that at the old base, Medicine Hat, at the C.P.R. Station.

Vermilion, Alta.—The station A-9 has a value of gravity 1.15 milligals less than that at the previous base at the Town Hall.

Saskatoon, Sask.—The previously adopted gravity stations were connected to A-10. The base at the Senator Hotel is 0.55 milligal less than that at A-10, and that at the University of Saskatchewan base is 3.20 milligals less than that of A-10.

Yorkton, Sask.—The station A-11 is 6.47 milligals greater than that at the previous base at the C.N.R. station and 7.02 milligals less than that at the previous base at the Post Office.

Swift Current, Sask.—The value of gravity at A-44 is 13.67 milligals less than that at the Courthouse gravity station.

Regina, Sask.—The value of gravity at A-43 is 0.30 milligal less than that at the previous base at the Canadian National Express Office.

Brandon, Man.—Three gravity stations had been used previously at Brandon. Relative to A-42, they have gravity valves (a) 3.82 milligals greater at the Experimental Farm, (b) 2.51 milligals less at the C.N.R. station and (c) 0.39 milligal less at the Ross Avenue base.

Portage la Prairie, Man.—The value of gravity at A-14 is 4.07 milligals less than that at the previous gravity base at the Island Park.

Neepawa, Man.—The value at A-12 is 1.17 milligals less than that at the previous gravity base at the C.P.R. station.

Winnipeg, Man.—The situation at Winnipeg is rather complicated. It was originally hoped to use a gravity base previously established at the RCAF side of the airport. This station was designated as A-13, but regulations demanded that the charter aircraft be parked at the civilian side of the field. Hence the station A-13X was established (Figure 3), and all the adjustments are referred to this station. It was found that station A-13X has a value of gravity which differs from other Winnipeg stations as follows:

Station	from A-13X (mgals.)
A-13	+0.12
Parliament Building	+0.25
Dominion Public Building, basement	+1.30
Dominion Public Building, Gravity base	+0.83
U.S.C.G.S. station	−0.02

The gravity differences listed above were derived during a subsequent adjustment of gravity base stations in the Prairie Provinces (Bancroft, unpublished).

Kenora, Ont.—The value of gravity at A-15 is 14.01 milligals less than that at the C.P.R. station.

Graham, Ont.—The value of gravity at A-16 is 5.75 milligals greater than that at a nearby railroad junction on highway 17.

Sioux Lookout, Ont.—The value of gravity was 8.20 milligals lower than that at the previously established base at the Masonic Hall.

Armstrong, Ont.—There has been no connection made from A-40 to other Dominion Observatory stations and therefore, for the purpose of computing the Bouguer anomaly, the elevation is estimated as 1050′ ± 5′.

Nakina, Ont.—The value of gravity at A-39 is 5.28 milligals less than that at nearby Cordingley Lake, a base used during previous surveys.

Port Arthur, Ont.—The value of gravity at A-17 is 4.07 milligals less than that at the Baptist Church gravity station.

Marathon, Ont.—A-18 is unconnected to other work.

Sault Ste. Marie, Ont.—The value of gravity is 4.68 milligals greater than that at the Post Office base.

Kapuskasing, Ont.—The value of gravity at A-38 is 0.76 milligal greater that than at the C.N.R. station.

Timmins, Ont.—The value of gravity at A-37 is 15.07 milligals greater than that at the C.N.R. station.

North Bay, Ont.—The value of gravity at A-36 is 27.39 milligals less than at the gravity base at the Bishop's Palace.

Sudbury, Ont.—The value of gravity at A-20 is 6.12 milligals less than that at the High School gravity base.

Toronto, Ont.—The station A-21 is identical with that described in a previous report (Innes & Thompson, 1953).

Trenton, Ont.—The station A-22 has a gravity value 0.16 milligal greater than that at the C.N.R. station.

Ottawa, Ont.—The adopted value of 980.62267 for the station A-24 was based upon a connection to the fundamental gravity pier where a standard reference value of 980.62200 is adopted for all gravity work of the Dominion Observatory. More recently, the author has measured and adjusted revised values for all connections in Ottawa (*see* Innes, 1958). These adjustments have the effect of making the value of gravity at A-24 equal to 980.62265, so that on this basis all the gravity values listed in Table 5 are 0.02 milligal too high. Since the discrepancy is less than the uncertainty, the values of gravity in the present report have not been changed.

Montreal, Que.—The station A-23 is virtually identical to that described in a previous report (Innes and Thompson, 1953).

Quebec, Que.—The value of gravity at A-25 is 12.76 milligals greater than that at the base of the Martello Tower.

Baie Comeau, Que.—The station A-26 is identical with that listed in a published report (Thompson and Garland, 1958).

Mégantic, Que.—The value of gravity at A-35 is 1.48 milligals less than at the C.P.R. station.

Chatham, N.B.—The station A-27 has a value of gravity 6.43 milligals greater than that at the base established by Garland (1953b) at the Newcastle C.P.R. station.

Fredericton, N.B.—The station A-34 is at present unconnected to other Dominion Observatory bases.

Moncton, N.B.—The station A-28 is unconnected to previously established stations.

Amherst, N.S.—The value of gravity at A-29 is 0.06 milligal greater than that at the Dominion Public Building Base.

Sydney, N.S.—The value of gravity at A-33 is 8.71 milligals less than that at the C.N.R. station.

Charlottetown, P.E.I.—The value of gravity at A-30 is 5.98 milligals less than that at the Court House.

Stephenville, Nfld.—The station A-31 is identical to that used by G. P. Woollard (1952).

Gander, Nfld.—The station A-32 has a value of gravity 0.10 milligal less than G. P. Woollard's station and a value 0.25 milligal less than that at a station used by L.G.D. Thompson.

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