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Gravity Determinations in 1936

BY

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ABSTRACT.—The object of the 1936 observations was to determine whether or not the Timiskaming earthquake of November 1, 1935, had been accompanied by a measurable change in gravity. For this purpose there were selected for redetermination the three existing gravity stations nearest to the epicentre and a group of three other stations at some considerable distance. A new station close to the epicentre was also occupied. The distances of the stations in the first group varied from 35 to 95 miles and those of the second from 215 to 280 miles. Although the results are not as conclusive as could be desired they nevertheless give no grounds for supposing a change in gravity to have occurred.

During the initial stages of the investigation into the Timiskaming earthquake of November 1, 1935, it was considered to have been of the deep-focus type. Though the occurrence of earthquakes of this type appears to be well established, the causes giving rise to them are more or less obscure. It has been suggested that if they are the result of, or are associated with, displacements of comparatively large underground masses, there is the possibility of small but perhaps appreciable changes in the force of gravity as measured at the surface in their vicinity. Since there were three previously occupied gravity stations at distances less than a hundred miles from the epicentre of the Timiskaming quake, this appeared to be a good opportunity to make such a test through repeat observations. On the other hand, these stations had been occupied a number of years ago, when instruments and methods were presumably not so accurate as today. It therefore appeared a wise precaution, for purposes of comparison, also to repeat observations at three other stations, so distant that they would not in any case be affected. The stations in the vicinity of the epicentre were Mattawa, New Liskeard, and Sudbury, at approximate distances of 35 miles, 65 miles, and 95 miles respectively. The comparison stations chosen were Kingston, Ste. Anne de Bellevue, and Montreal, distant respectively 215 miles, 265 miles, and 280 miles. A new station was established at Timiskaming.

Two standardizations of the pendulums were made at Ottawa, one at the beginning and the other at the conclusion of the work. Each consisted of not less than twenty-four 12-hour swings, while the field determinations were made with not less than twelve 12-hour swings at each place. Two knife edges and three pendulums were used. At the observatory the pendulums were timed, by means of the flash apparatus, from a relay operated by the slave of the Shortt clock. In the field the flash apparatus was operated by a gaining chronometer (1 second in 50), which in turn was rated by comparison at least twice daily with the N.A.A. wireless time signals on wave lengths of 32.4 and 36.8 metres.

With the exception of Mattawa and New Liskeard the redeterminations were made in the same buildings as the original determinations. At Mattawa the building in which the previous determination was made had been burned down, and at New Liskeard the original building was not available for such work. It is only at Mattawa, however, that (after correction for elevation and latitude differences) we may not safely regard the old and the new determinations as though they had been made at the same spot in each case. Here there is an uncertainty due to change of position which might, but would not likely, amount to more than .005 c.g.s. units.

DISCUSSION OF THE RESULTS

The results of the observations are summarized in the accompanying three tables. Periods of the pendulums, in mean time seconds, are given for individual surveys in Table 2. The mean periods of each pendulum and the corresponding deduced values of gravity are given in the last two lines for each station. Comparisons of the old and new determinations of gravity are given in columns 2 and 3, Table 3. The probable errors were obtained by considering the probable error for any field station as a combination (square root of the sum of the squares) of the following probable errors: (1) the probable error of the mean value of gravity deduced from the results for that station in Table 2 of this paper, or from Table 4, Pub. D.O., 11, No. 3, 1936; (2) the probable error of the mean value of the periods of the pendulums deduced from the pre-season and post-season standardizations (at Ottawa) expressed in terms of g ; (3) the probable error (amounting on the average to only $\pm .0002$) due to flexure, also obtained by combination of the probable errors of the field and base station determinations of the flexure. The real probable errors would in all likelihood be somewhat in excess of these values.

Table 3 shows that for Sudbury and Montreal the differences (column 4) are of the same order of magnitude as their probable errors. It would appear that, if any change in gravity occurred at these stations, it was by an amount beyond the sensitivity of the measurements. The probable error of the determination at Timiskaming is $\pm .0004$ c.g.s. units. No attempt has been made to ascribe probable errors to the measurements made at Mattawa, New Liskeard, Kingston and Ste. Anne de Bellevue in 1914. These were liable to considerable error owing to the unsatisfactory behaviour of the pendulums during that season, due to the fact that the stems had not at that time been rivetted to the bobs.¹ It now seems likely that variations occurred in the pendulums during 1914 which were not apparent from the observations.

The results of the investigation therefore cannot be taken to indicate definitely any variation in gravity. Everything considered, the observed differences of $.008$ and $.006$ at Mattawa and New Liskeard are not excessive. There is definite indication of no change at Sudbury. It would seem to be a reasonable conclusion that there has been no demonstrable change in gravity due to the earthquake.

Attention may be directed to the large isostatic anomalies at Mattawa and Timiskaming (Table 1). There is lack of topographic maps at both these stations, but the error arising from this cause is not likely to exceed $.005$ in either case.

RELATION OF GRAVITY TO EARTHQUAKES

Except from a general point of view little attention seems to have been given to this subject. In Japan consideration has been given to the relation of time variations of the gravity gradient to volcanoes and earthquakes. Repeat observations were made with torsion balances. It does not appear that any very definite conclusions were reached.²

It has been suggested³ that changes in the periods of gravity pendulums at the gravity base (Dehra Dun) in India might have been related to possible variations in

¹ Pub. D.O. 2, No. 10, pp. 239, 240 and 266, 1915; 3, No. 9, pp. 357, 358 and 363-365, 1918.

² Rept. Imp. Jap. Geod. Comm., Nos. 7, 8, 9, 1926, 1927.

³ Nature, 110, 665, 874, 875, 1922.

gravity at that place. This was later attributed to changes in the pendulums themselves combined with observation error.

S. Heller¹ reports on a seismic area in Europe. Gravity observations repeated, in 1934, after an interval of thirty years show a difference of $\cdot 020$. A relation between earthquakes and displacement of matter, presumably accompanied by detectable variations in gravity, is suggested by the author.

In accepting the results of any pendulum measurements it is well to adopt a cautious attitude, especially where small differences are involved, as it is known "that many apparently irreproachable gravity observations have in the past been found to be subject to unexpected and unexplained errors."²

DESCRIPTIONS OF STATIONS

No. 129, Mattawa, Ont. (1936).—The apparatus was set up on the concrete floor in the southwest part of the coal bin of Mattawa hospital. Measured from the inside of the foundation walls, the station was 1 foot 10 inches from the south wall and 4 feet 5 inches from the west wall. It was 11 feet below the elevation of G.S.C. B. M. MDLXXXIII in the Roman Catholic church. It was 12 feet below and approximately 2,300 feet north and 1,600 feet west of the station established by F. A. McDiarmid in 1914, the distances being scaled from the plan (kept in the town hall) of the municipality of Mattawa on a scale of 4 miles to an inch.

No. 102, Sudbury, Ont. (1936).—The apparatus was set up on the same spot as that occupied during the season of 1927. For description see Publications of the Dominion Observatory, Vol. XI, No. 3, p. 91. Measured from the inside of the walls of the assay room, the station was 13 feet from the south wall, which is part of the south wall of the building, and 4 feet 9 inches from the east wall, which forms the partition between the assay and milling rooms.

No. 130, New Liskeard, Ont. (1936).—The apparatus was set up on the concrete floor of the basement of the Post Office. The station was situated at a point approximately in the centre of the building, in the large room on the south side of the basement. Measured from the inside of the foundation walls, it was 21 feet from the south wall and 33·8 feet from the west wall. It was 0·2 feet above the elevation of G.S.C.B.M. MDCLIV in the Grand Union hotel. It was 10·5 feet above and approximately 136 feet north and 370 feet west of the station established in the Library by F. A. McDiarmid in 1914, the distances being measured from Sutcliffe's plan of the town of New Liskeard on a scale of 300 feet to an inch.

No. 131, Timiskaming, Que. (1936).—The apparatus was set up on the concrete floor in the northwesterly part of the basement of the Roman Catholic church. Measured from the inside of the foundation walls, the station was 13·9 feet from the north wall and 41·5 feet from the west wall. It was 88 feet above the level of the rail at the Canadian Pacific Railway station across Gordon Creek from the foot of Humphrey Street.

¹ Zeit. f. Geoph. 12, G.B. 97, 1936.

² E. C. Bullard, Phil. Trans. R.S. Series A, Vol. 235, p. 473, 1936.

- No. 2, Kingston, Ont. (1936).—The apparatus was set up in the City Hall on the concrete floor in the southwest corner of the small room adjoining the boiler room to the south. It was 9 feet below the elevation of G.S.C.B.M. No. 141A in the Clarence Street wall of the Post Office. From the description of the station occupied in the same building in 1914, it is judged that it is about 30 feet southeast of and $2\frac{1}{2}$ feet higher than the station established by F. A. McDiarmid.
- No. 8, Ste. Anne de Bellevue, Que. (1936).—The apparatus was set up on the concrete floor approximately in the centre of room 5 in the basement of the Physics and Chemistry building of Macdonald College. This room is on the west side of the building and is reached by the third door leading off the corridor from the north end of the basement. From levels taken by J. E. McMynn, student in Engineering of McGill University, and by A. H. Miller, it was found that the gravity station was 23.8 feet above the elevation of G.S.C.B.M. CCCCVIII in the west foundation wall of the dwelling on the south side of the highway at the corner of Ste. Anne's road and Maple Avenue. The station is in the same building as that established by F. A. McDiarmid in 1914 and is presumed to be at the same elevation.
- No. 116, Montreal, Que. (1936).—The apparatus was set up in the same room as that in which the station of 1928 was established. It was within not more than six feet of the site of the previous station and at the same elevation. For description see Publications of the Dominion Observatory, Vol. XI, No. 3, p. 93.
- No. 1, Ottawa, Ont. (1936).—The apparatus was set up on the concrete pier in the pendulum room of the Dominion Observatory. It is 34 feet south and 100 feet east of the meridian circle and 6.4 feet below the elevation of G.S.C.B.M. No. 125A in the south wall of the observatory. Standardizations have been made on this pier since and including the season of 1915. In 1914 the standardizations were made on a pier (demolished in 1929) in the room in the southwest corner of the basement. (See Fig. 1, following p. 211, Report of the Chief Astronomer, 1905). Measured from the inside walls of this room the centre of the demolished pier was 4 feet from the south wall and 5 feet from the west wall. It was 13 feet north and 54 feet west of the pier in the pendulum room. The tops of the two piers were within a few inches of the same elevation.

DOMINION OBSERVATORY,
OTTAWA, April 1937.

TABLE 1—PRINCIPAL FACTS FOR GRAVITY STATIONS ESTABLISHED DURING 1936

Number and Station	Longitude	Latitude	Altitude		Computed Gravity at Sea Level	Corrections for		Computed Gravity	Observed Gravity	Gravity Anomalies		
			Ft.	M.		Altitude	Topography and Isostatic Compensation			Hayford 113.7 km.	Free Air	Bouguer
1 Ottawa.....	75 43.0	45 23.6	272	83	980.665	-.026	-.008	980.631	980.622	-.009	-.017	-.026
129 Mattawa.....	78 42.6	46 19.1	541	165	980.748	-.051	-.007	980.690	980.648	-.042	-.049	-.068
102 Sudbury.....	81 00.0	46 29.8	885	270	980.764	-.083	+.002	980.683	980.683	.000	+.002	-.028
130 New Liskeard.....	79 40.3	47 30.6	613	187	980.856	-.058	-.005	980.793	980.785	-.008	-.013	-.034
131 Timiskaming.....	79 06.0	46 43.0	830	253	980.784	-.078	+.001	980.707	980.681	-.026	-.025	-.053
3 Kingston.....	76 28.8	44 13.6	257	78	980.560	-.024	-.004	980.532	980.524	-.008	-.012	-.021
8 Ste Anne de Bellevue.....	73 56.6	45 24.5	104	32	980.666	-.010	-.010	980.646	980.645	-.001	-.011	-.015
116 Montreal.....	73 34.5	45 30.3	137	42	980.675	-.013	-.009	980.653	980.650	-.003	-.012	-.017

TABLE 2—PENDULUM PERIODS AND DEDUCED VALUES OF GRAVITY

Number and Station	Number of swings	Knife Edge I			Knife Edge II			Mean	
		Pendulum			Pendulum				
		1	2	3	1	2	3		
1 Ottawa (June-July 1936).....	25	.4999745	.5000820	.5000599	.4999705	.5000788	.5000567	.5000370 980.622	
		.4999742	.5000821	.5000605	.4999703	.5000787	.5000564		
		.4999742	.5000824	.5000601	.4999706	.5000788	.5000564		
		.4999745	.5000825	.5000593	.4999701	.5000784	.5000565		
			.5000591						
		.4999743	.5000823	.5000598	.4999704	.5000787	.5000565		
g									
129 Mattawa (2).....	15	.4999667	.5000753	.5000539	.4999641	.5000721	.5000497		.5000303 980.648
		.4999672	.5000751	.5000532	.4999638	.5000718	.5000498		
		.4999669					.5000507		
					.5000501				
		.4999669	.5000752	.5000536	.4999640	.5000720	.5000501		
g	980.650	980.648	980.646	980.648	980.649	980.648			
102 Sudbury.....	13	.4999588	.5000662	.5000448	.4999548	.5000638	.5000416	.5000215 980.683	
		.4999578	.5000661	.5000445	.4999552	.5000632	.5000410		
					.4999548				
		.4999583	.5000662	.5000447	.4999549	.5000635	.5000413		
g	980.684	980.684	980.681	980.684	980.683	980.682			
		.4999323	.5000404	.5000187	.4999294	.5000376	.5000151		
130 New Liskeard (2).....	13	.4999323	.5000401	.5000187	.4999289	.5000375	.5000149	.4999955 980.785	
		.4999324							
		.4999323	.5000403	.5000187	.4999292	.5000376	.5000150		
g	980.786	980.785	980.783	980.785	980.784	980.786			

131 Timiskaming.....	12	.4999585	.5000668	.5000451	.4999557	.5000634	.5000416	
		.4999586	.5000668	.5000453	.4999560	.5000639	.5000418	
		.4999586 g 980.682	.5000668 980.681	.5000452 980.679	.4999559 980.680	.5000637 980.682	.5000417 980.681	.5000220 980.681
3 Kingston.....	12	.4999991	.5001064	.5000849	.4999957	.5001041	.5000817	
		.4999990	.5001065	.5000850	.4999956	.5001039	.5000818	
		.4999991 g 980.524	.5001065 980.526	.5000850 980.523	.4999957 980.524	.5001040 980.524	.5000818 980.524	.5000620 980.524
8 Ste Anne de Bellevue.....	12	.4999675	.5000757	.5000539	.4999652	.5000733	.5000513	
		.4999681	.5000760	.5000540	.4999650	.5000735	.5000511	
		.4999678 g 980.646	.5000759 980.646	.5000540 980.645	.4999651 980.644	.5000734 980.644	.5000512 980.644	.5000312 980.645
116 Montreal.....	12	.4999667	.5000748	.5000531	.4999640	.5000721	.5000503	
		.4999672	.5000745	.5000525	.4999640	.5000728	.5000503	
		.4999670 g 980.649	.5000747 980.650	.5000528 980.649	.4999640 980.648	.5000725 980.647	.5000503 980.647	.5000302 980.649
1 Ottawa (October 1936).....	24	.4999737	.5000814	.5000597	.4999708	.5000792	.5000567	
		.4999737	.5000814	.5000601	.4999710	.5000791	.5000571	
		.4999736	.5000815	.5000598	.4999708	.5000791	.5000570	
		.4999741	.5000814	.5000600	.4999712	.5000792	.5000571	
		.4999738 g5000814500059949997105000792500057050003705 980.622
1 Ottawa, Adopted periods for 1936.....		.4999740	.5000819	.5000598	.4999707	.5000790	.5000567	.5000370

TABLE 3—DEDUCED VALUES OF GRAVITY FOR STATIONS REPEATED IN 1936

Station	Previous value referred to 1936 position	Value obtained in 1936	Difference
Mattawa.....	980·656	980·648 ± ·0004	--·008
Sudbury.....	980·684 ± ·0010	980·683 ± ·0004	--·001 ± ·001
New Liskeard.....	980·791	980·785 ± ·0004	--·006
Kingston.....	980·534	980·524 ± ·0003	--·010
Ste Anne de Bellevue.....	980·667	980·645 ± ·0003	--·022
Montreal.....	980·652 ± ·0018	980·649 ± ·0004	--·003 ± ·002

