INTERNATIONAL GEODETIC AND GEOPHYSICAL UNION

First General Conference, Rome, 1922

Canada

THE

GEODETIC SURVEY OF CANADA

Operations

April 1, 1912, to March 31, 1922

BY

NOEL OGILVIE

SUPERINTENDENT, GEODETIC SURVEY OF CANADA
DEPARTMENT OF THE INTERIOR
OTTAWA, CANADA

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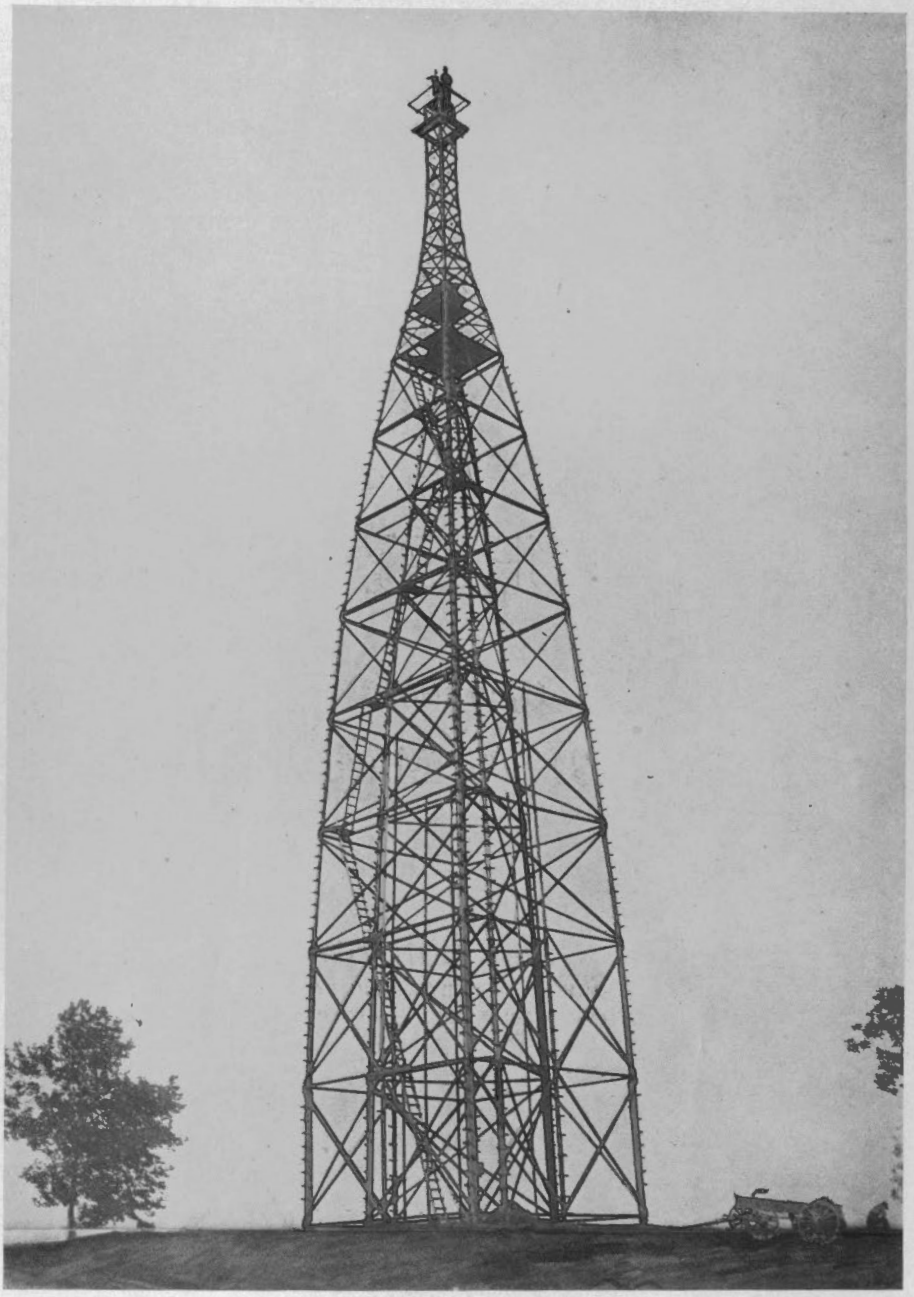

147-ft. Tower near Chatham, Ont., Height of Tripod, 110 feet.

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THE GEODETIC SURVEY OF CANADA. OPERATIONS, APRIL 1, 1912 TO MARCH 31, 1922

BY

NOEL OGILVIE, SUPERINTENDENT, GEODETIC SURVEY OF CANADA
DEPARTMENT OF THE INTERIOR, OTTAWA, CANADA

INTRODUCTION.

The Geodetic Survey of Canada was commenced in 1905, and its activities have been continually extended up to the present time. Its operations consist of triangulation, precise traverse, precise levelling and city mapping.

To the end of 1921 the total area of completed triangulation field work is approximately 140,000 square miles (360,000 sq. km.), 65,000 square miles (170,000 sq. km.) of this total having been partly finished prior to 1912. In addition to the completed triangulation a start has been made on 80,000 square miles (210,000 sq. km.). The reconnaissance, or selection of stations, is all that has been accomplished in this area.

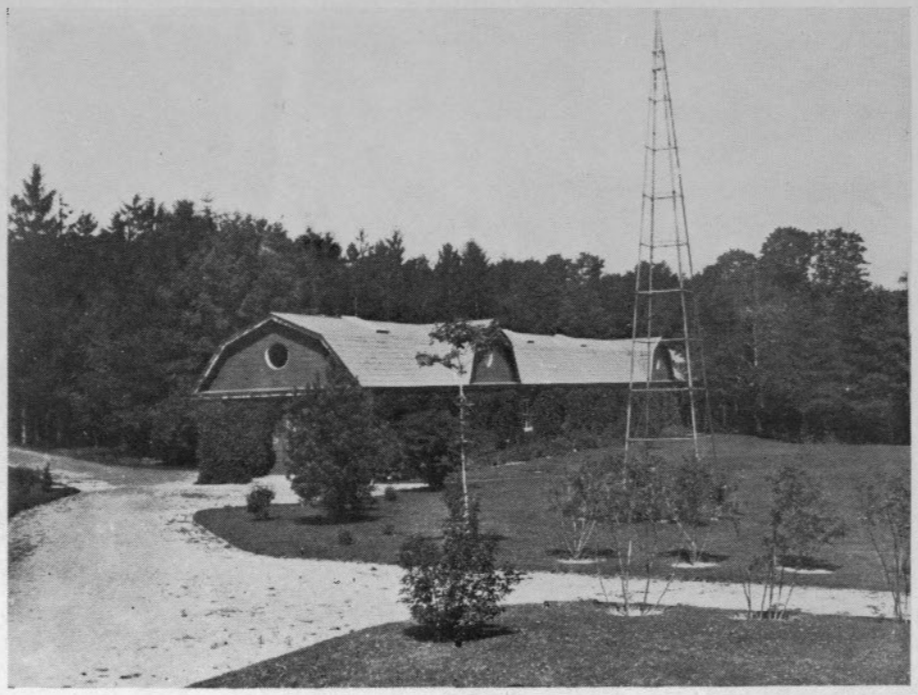
Published data cover only a portion of the above areas, but final results in course of preparation for publication will largely augment the total already published. It is the policy of the Survey to publish only data which is finally adjusted, but preliminary results, which may depend on only part of the field data, are distributed as the information is required.

Closely allied to triangulation is precise traverse work. An economical and accurate substitute for primary triangulation was desirable in flat wooded country covered by roads or railroads, where the high cost of primary triangulation was a serious factor. Precise traverse measurement fills a useful place by supplementing or substituting for primary triangulation where conditions are unfavourable for triangulation and suitable for traverse.

To date 15,016 miles (24,166 km.) of precise levelling of a high grade of accuracy has been completed by the Geodetic Survey of Canada, 12,389 miles (19,938 km.) having been finished since April 1, 1912. The adjusting of this large amount of levelling, together with 3,475 miles (5,595 km.) of precise levelling by other Canadian organizations, is in progress, and adjusted results will be available in the near future.

A need has become pressing in Canadian municipal life for adequate large scale maps of the bigger cities. In order that the requirements may be studied and methods evolved for handling the situation, the Geodetic Survey, in addition to having given control points to a number of cities—Montreal, Quebec, Toronto, etc. (see page 20), has in progress the actual detailed topographical survey of London, Ontario, the expense of which is divided between the city of London and the Geodetic Survey.

Geodetic Survey of Canada; Offices of 980 Carling avenue, Ottawa.



Standardizing Building of the Geodetic Survey, Ottawa.

GEODETIC OPERATIONS FROM APRIL 1, 1912 TO MARCH 31, 1922.

TRIANGULATION.

For a long time previous to 1905 efforts were made towards commencing a Geodetic Survey in Canada, and finally in 1905 these efforts were successful and the late Dr. W. F. King was authorized to commence triangulation and precise levelling operations in the vicinity of Ottawa.

In 1909 the Geodetic Survey of Canada was organized by Order in Council and Dr. King was given the title of Superintendent.

In 1914 a special building was completed for the use of the Survey staff.

During the summer of 1905 a portion of the country in the vicinity of Ottawa was explored for the purpose of selecting stations for the angular points of the triangulation system. During 1906 this work was expanded southward and eastward, and, as the level nature of the country and the tall trees required the erection of towers from which to take the necessary observations, a tower building party was organized and started in these operations.

The year 1907 saw the commencement of the observing of the horizontal angles. Reconnaissance for the selection of stations was also extended both east and west of Ottawa.

By the fall of 1908 angular measurements had been carried westward as far as Toronto and eastward into the province of Quebec. This year also saw reconnaissance started on the Atlantic coast in the Bay of Fundy region. In 1909 reconnaissance was started along the Pacific coast in British Columbia and the Lake Superior district in the region of Port Arthur, westward along the International boundary between the United States and Canada.

In 1910 and 1911 angular measurements were commenced in the Port Arthur and British Columbia coast regions respectively.

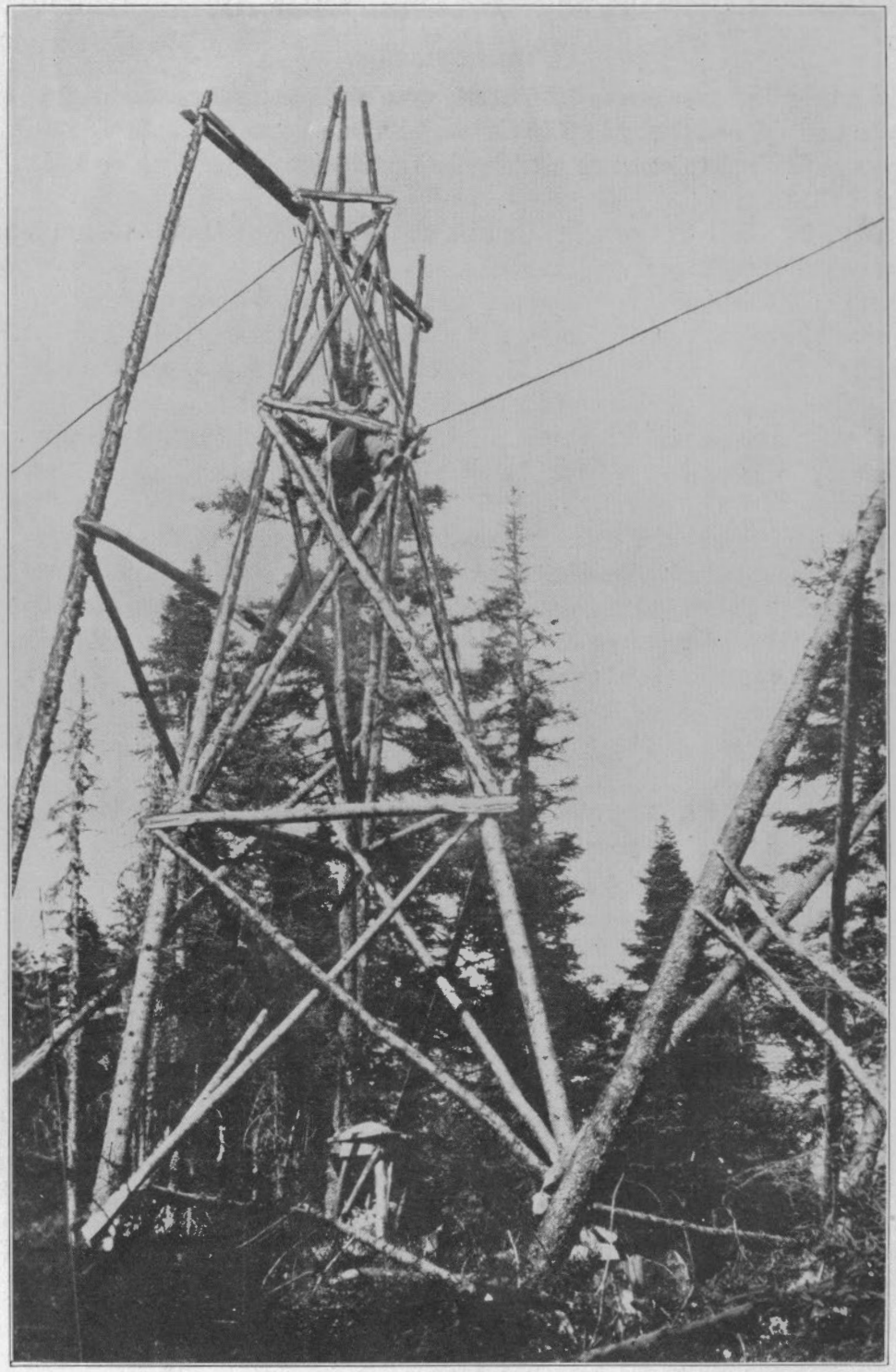
In 1910 a Geodesist's office was established in order that field data might be adjusted and harmonized before being published, and geodetic methods studied and applied to the direction and improvement of field methods. By 1912 the total triangulation on which angular measurements were completed was approximately 65,000 square miles (169,000 sq. km.) with reconnaissance surveys extending over almost as large an additional area.

Up to 1912 one base line had been selected and measured but no Laplace points (coincident triangulation, longitude and azimuth stations) had been occupied.

From 1912 to March 31, 1922, operations have been carried on more or less continuously in all sections of the Dominion, with the exception of the three provinces of Manitoba Saskatchewan and Alberta. The triangulation operations in the latter three provinces were commenced in 1920 and have been energetically proceeded with.

To March 31, 1922, the field work of some 2,000 miles (3,200 km.) of primary triangulation has been largely completed, the average width of the nets being about 70 miles (112 km.).

In the triangulation accomplished since 1912 eight new base lines have been selected and measured, making a total of nine to date, while fifteen Laplace stations have been



Rough and Ready Tower Building in Eastern Quebec for sighting over local timber.

established, all between 1912 and March 31, 1922. Base lines have been 200 miles (320 km.) apart on the average, while the Laplace stations have averaged about seven geometrical figures apart.

The triangulation consists of primary and secondary schemes (as represented by average triangle closures of less than 1 second and 2.5 seconds respectively), and has been used to control the geographical position and accuracy of topographic and hydrographic surveys of other departments of the Federal Government, the mapping done in connection with cadastral surveys of Provincial Governments, as well as the surveys and maps of cities, private companies and individual engineers.

The map at the end of this publication shows the extent of the primary triangulation nets in Canada. It will be noticed that the area covered by the triangulation has been such as to give control to topographic and hydrographic surveys along our waterways and in the more densely settled parts of the country. This is, of course, the direct function of the Geodetic Survey of Canada. The scientific problems which may be solved from the field data secured, although very important, are of relatively secondary consequence to the economic value of survey results.

Three co-operative features have marked the recent operations of the Geodetic Survey of Canada, in addition to the increasing co-operation which is in evidence between this survey and other organizations. These features, as all co-operative movements should, have resulted in economy and the increased usefulness of geodetic operations.

The first of these features deals with general co-operation with the United States Coast and Geodetic Survey. Along the Pacific coast the two organizations are working on a co-ordinated scheme of triangulation through northern United States, British Columbia, southeastern Alaska, Yukon and the main part of Alaska, which will take a number of years to complete. In this manner these various parts of Canadian and United States territory will be connected with the North American Datum*.

*See page 10.

Another net is that along the International boundary from lake Superior to lake of the Woods; the Canadian half of this section was completed in 1917, while the United States share is now in progress.

The latest example of this co-operation is shown in the arrangement by which primary triangulation is being projected along the International boundary between the United States and Canada, from lake of the Woods to the Pacific ocean, by their national geodetic surveys. Under this arrangement the total distance of about 1,250 miles was divided between the two organizations, the Canadian survey taking the eastern, and the United States survey the western half. Had this arrangement not been made it was the intention of the United States organization to extend an east and west triangulation net a short distance south of the boundary, while a similar east and west net not far north of the boundary had been on the programme of the Canadian survey since its inception. One triangulation net along the boundary would obviously serve the purposes of both countries almost as well as separate schemes—at least economy of the co-ordination was

self evident—so that the above arrangement was made in 1921 and will be continued to completion.

It is also to be noted that lines of precise levels which have been run by the national geodetic organizations of the United States and Canada will strengthen the precise level nets of the two countries.

The second co-operative aspect is in connection with the Provincial Forest Services, with two of which agreements have been made for a division of the cost of towers which are required by this survey on certain triangulation stations to obtain the necessary intervisibility of stations, and by the Forest Service as lookout towers for the detection and localization of forest fires. This arrangement is advantageous to the provinces concerned where the building programmes of the two organizations coincide, as the stations selected for geodetic purposes are in general admirably suited to the location of fire detection towers; hence, the cost of reconnaissance is saved. It is advantageous to both organizations in that one tower serves two purposes and the cost of both operations is thereby reduced.

The third co-operative feature is that whereby the triangulation and precise levelling required in cities and other vicinities for the production of city maps and plans is carried on by the Geodetic Survey of Canada. The Survey provides the engineer and his instruments, while the city concerned pays for all materials, labour, etc., in connection with this work. It is found that city engineering staffs are generally insufficiently provided, both in training and suitable instruments, to undertake this control work efficiently; hence, it was desirable that arrangements be made whereby the one organization in Canada which is specially trained in these operations—the Geodetic Survey—can assist the cities in the ground work at least of this very important work.

NORTH AMERICAN DATUM.

It is important that the triangulation be all based upon the same initial point in order to avoid the errors due to the deflection of the plumb line at the various stations. This starting of all surveys from the same initial point and on the same sized spheroid, brings into play what is known as the North American Datum, which may be explained as follows:

Early in the year 1913 a conference took place between the Superintendent of the United States Coast and Geodetic Survey, the Superintendent of the Geodetic Survey of Canada, and the Director of the Mexican Geodetic Survey. The two latter adopted what was then known as the United States Standard Datum as the datum for their respective surveys, with the consequent use, as heretofore, of the Clarke spheroid of 1866 by all three organizations.

On account of the international character of this adopted datum, the name was changed from the United States Standard Datum to the North American Datum.

This decision to adopt the North American Datum as the datum for the results of the Geodetic Survey of Canada is such an important one, and so far-reaching in its effects, that it demands some explanation.

After the errors of a triangulation system have been adjusted the resulting angles and the distances between stations are used to compute the latitudes and longitudes of all

the triangulation stations. These computations must be started from a station at which the latitude, longitude, and the direction to some other station are known. Also computations must be based on certain dimensions for our spheroidal shaped earth. Then the datum for the geographical co-ordinates (latitude, longitude and azimuth) throughout that system of triangulation is the position of that system on the particular sized earth which is assumed to be the correct one, and is defined by the co-ordinates of the station from which the computations started.

Thus the selection of a datum depends on a balance of astronomic and geodetic results. These astronomic results are, however, subject to errors which may be many times the errors of observation. This is due to the deviation of the plumb line at the points of observation, caused by the attraction of unequally distributed densities, such as mountains, lakes, valleys and sub-surface dense masses. The triangulation in Canada had to be started at widely separated points. If a different datum were used at each of these starting points, and if one of these did not accord with the others, the triangulation based upon it would be twisted. Serious overlapping would occur where the different systems were joined.

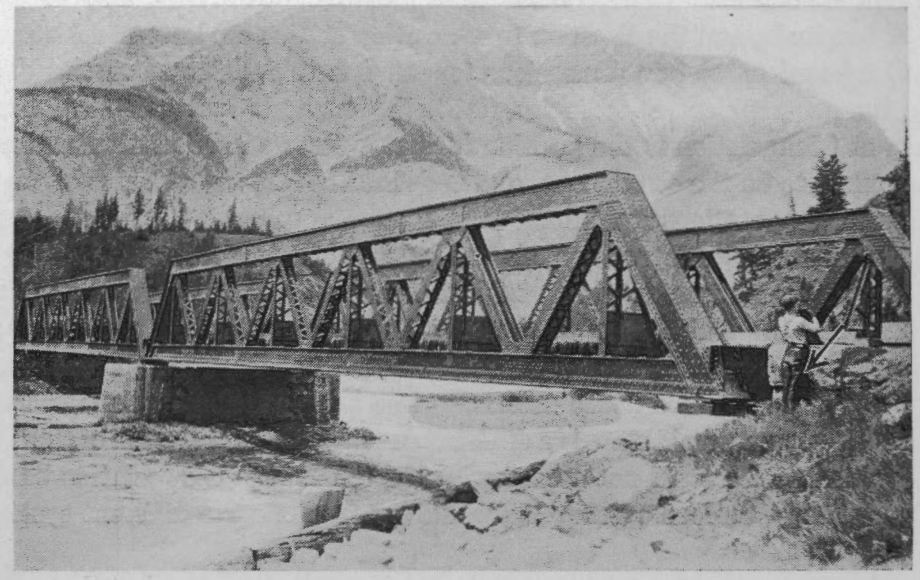
That these discrepancies might be serious may be seen from the fact that astronomically determined positions have, in Canada, already been found to be in error by as much as half a mile due to the deviation of the plumb line as outlined above.

Thus it will be seen that it is necessary to establish a datum which is very close to the truth. The only method by which a correct datum may be determined is to have many astronomical stations scattered over the country and to have them connected by triangulation. By this means the anomalies due to the deviation of the plumb line may be detected. The most probable position of the initial point to which the whole triangulation is referred, and by which the position of the triangulation is governed, may thus be determined. It may easily be realized that thirty or forty years might elapse before a final datum could be selected for Canada.

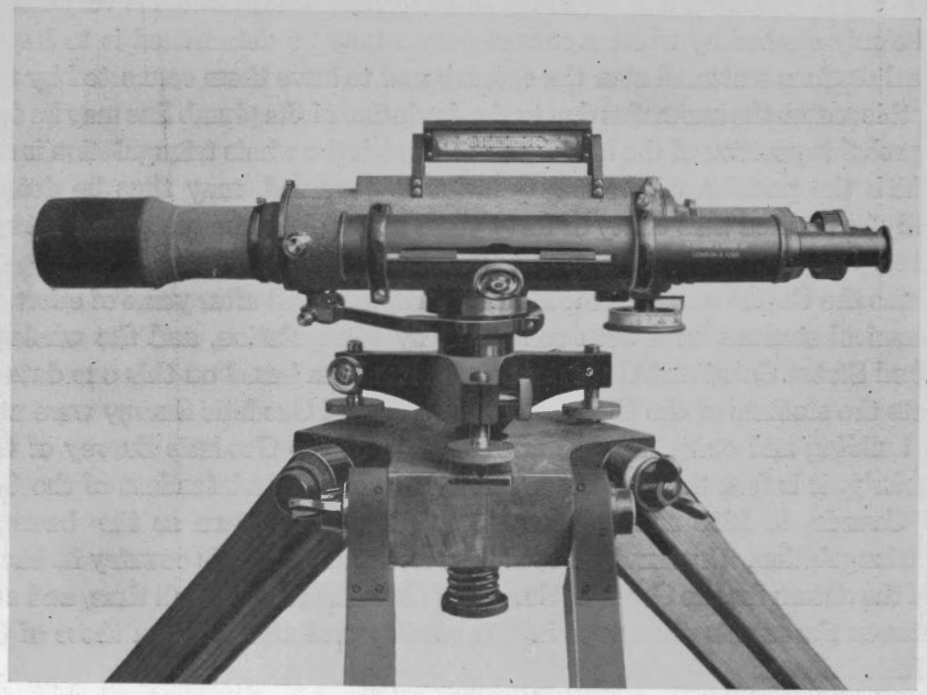
Thus was the United States Standard Datum determined after years of effort. Some 600 astronomical stations have been connected by triangulation, and the whole system of the United States Coast and Geodetic Survey has been based on this one datum. At many points the stations of the United States Coast and Geodetic Survey were available for use in building and correcting the triangulation of the Geodetic Survey of Canada, and very wisely, it is felt, the late Dr. W. F. King, then Superintendent of the Geodetic Survey of Canada, in 1913 adopted the North American Datum as the basis for the Canadian triangulation, thus saving much time and money to this country in having the question of the datum for the Geodetic Survey of Canada settled for all time, and avoiding clashes between the results of surveys in this country and also between those of Canada and the United States.

Precise Levelling.

Precise Levelling was started in 1906 and has been carried on year by year with an average of from four to five parties in the field each summer. Owing to climatic conditions the parties do not in remain the field, as a rule, for more than about six months in each year.



Establishing a Bench-mark in a bridge abutment on the Canadian Pacific railway near Banff, Alta.



Precise Level of the Geodetic Survey of Canada—United States Coast and Geodetic Survey Pattern.

The instrument used throughout the work is a precise level of the United States Coast and Geodetic Survey pattern. Specially constructed rods, built up of strips of white pine boiled in paraffin, are used, but at the present time (March 31, 1922) these are being replaced by rods carrying the graduations on a strip of invar, the wood not having been found altogether reliable under varying weather conditions. The unit used in subdividing the rods is the yard (0.9144 metre), the smallest division being one one-hundredth of a yard (0·9144 cm.) and the readings being made by estimation to thousandths of a yard; previously the foot (0·3048 metre) was used as a unit, this unit also being subdivided into hundredths. The yard has been found to be a very satisfactory unit.

The standard bench-mark consists of a copper bolt set horizontally in solid rock, masonry or concrete or placed vertically in the top of a specially constructed concrete pier. In selecting sites for these piers every effort is made to so place them as to be secure from disturbance in the future. They extend about 6 feet (1·8 metres) below the ground surface in order that they may be safe from the effects of frost.

At the present time 4,544 bench-marks of the standard copper bolt type have been established—this number not including those permanent bench-marks of other organizations whose elevations have been determined by this Survey. On each copper bolt are stamped the initials of the Survey and the letters "B.M." (bench-mark); also the serial number of the bench-mark.

By March 31, 1922, 15,016 miles (24,166 kilometres) of precise levelling had been accomplished, every line being levelled both forward and backward. Of the above amount 12,389 miles (19,938 kilometres has been done since the beginning of 1912. In carrying on the levelling the usual procedure is for the same field party to run both the forward and backward levelling— this being done in sections of from 15 to 25 miles (24 to 40 kilometres). It is aimed to have bench-marks at intervals of 3 miles (4·8 kilometres) or less, and the instructions issued to the geodetic engineers require that the levelling in the two directions should agree within a limit of 0·017 foot $\sqrt{M}$, "M" being the distance in miles between adjacent permanent bench-marks. This corresponds to the limit of 4 mm. $\sqrt{K}$, where "K" is the distance in kilometres.

All elevations are on a mean sea-level datum and are based on five principal tidal stations—three on the Atlantic coast and two on the Pacific—and all the lines of levelling, except one comparatively short line in the Yukon territory, are connected together so as to form one system. Each of the nine provinces of the Dominion, with the exception of the insular province of Prince Edward Island, is included in the precise level net, and this net at the present time contains some 50 circuits or loops of levelling and is connected with the precise level system of the United States Coast and Geodetic Survey at several points along the International boundary.

About 94 per cent of the total amount of levelling has been carried along the tracks of the various railway companies, these tracks forming in many cases the only available routes for running levels.

Reference to the map at the end of this publication will show the extent of the precise level net and the routes followed by the various lines.

Geodetic Astronomy.

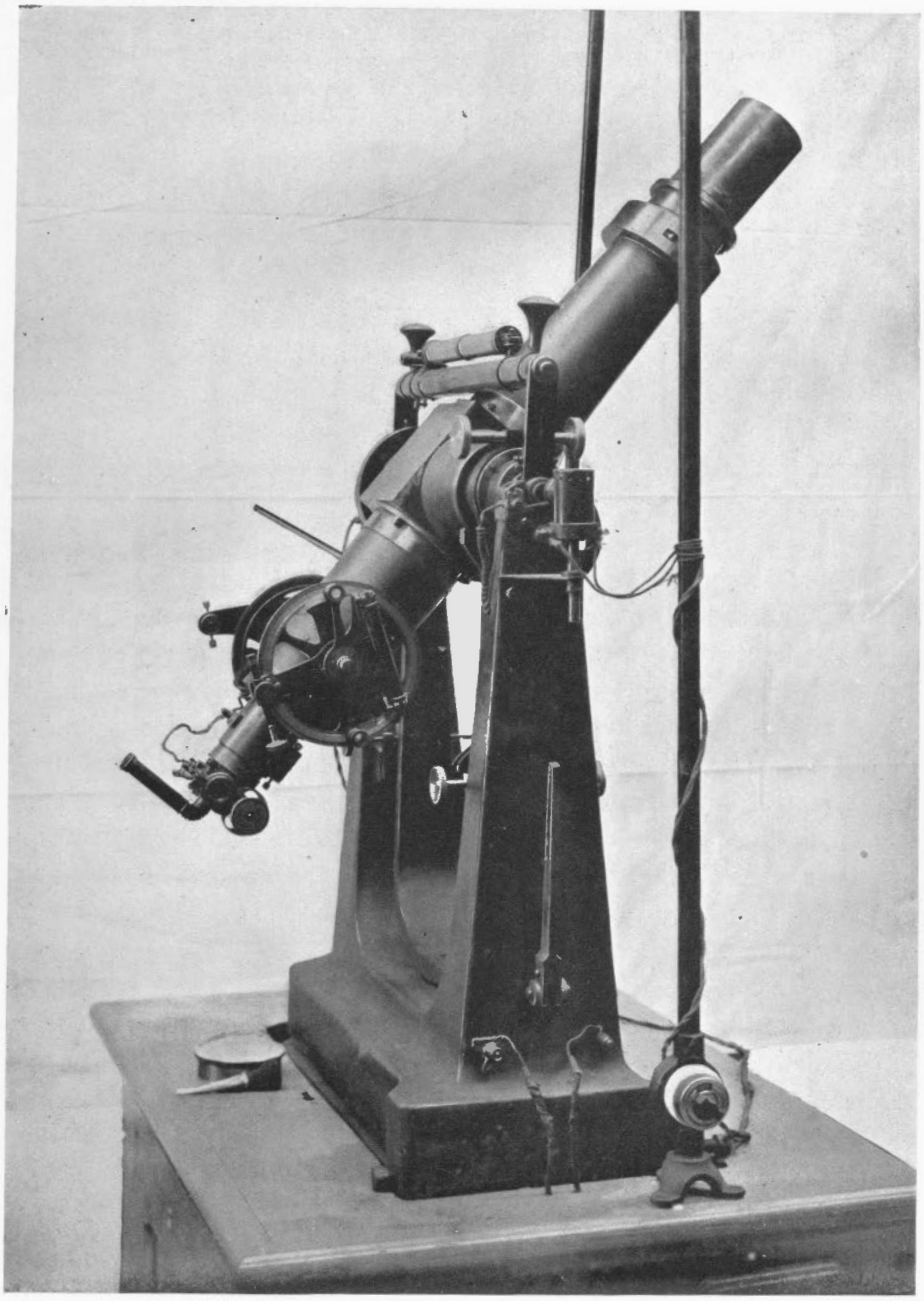
Geodetic Astronomy in Canada during the last ten years (January 1, 1912 to December 31, 1921) consisted in determinations of the longitude, latitude and azimuth at fifteen of of the triangulation points of the Geodetic Survey, and of the latitude and longitude of one station of the Alberta-British Columbia provincial boundary line. The longitude and azimuth observations at geodetic points furnish data from which to derive the Laplace or true geodetic azimuths, and along with the latitude, the deviations of the vertical.

The astronomical observations for longitude, latitude and azimuth are always made by the same observing party. The advantage of this is to ensure trained and experienced observers. Before and after a longitude campaign there are taken observations for personal equation between the field observer and the Riefler clock of the Dominion Observatory as given by the clock curve deduced from the meridian circle observations. This personal equation is of such magnitude that it is absolutely necessary that it be determined and applied to the longitude differences. Between the observer engaged in geodetic astronomy and the Riefler clock as determined by the Observatory for the past five years there has been a relative personal equation of about seven hundredths of a second of time.

LONGITUDE.

The base of the longitude determinations of the Geodetic Survey is the west pier in the transit house of the Dominion Observatory at Ottawa.

The longitude of this pier has been deduced by a solution of some eight longitude triangles, in which solution the positions of three points of the United States longitude net were considered as fixed, namely Harvard College, Montreal and Seattle. The type of instrument used in all the longitude determinations is the Cooke's astronomical transit fitted with a travelling wire micrometer on which the cut outs are so arranged that ample time is given for observing the stars before and after passing the meridian and reversing the instrument in its wyes between the two observations. The mean of the two sets of observations will give a result free from collimation. Each time set consists of from twelve to fifteen stars, four of which are of declination greater than seventy-two degrees north and the remainder lie between north declination twenty degrees and the zenith. In determining longitude two sets are taken on each night and an exchange of time signals is made with the base station between the sets. Five nights are required for the determination of a primary longitude, and the probable error of a difference of longitude so determined rarely exceeds one-hundredth of a second of time. At all except one station, Emily in the Port Arthur triangulation net, signals were exchanged over the telegraph line between Ottawa and the field point. At Emily the longitude was determined by wireless, the signals from the United States station at Arlington near Washington, D.C., being used as arbitraries. Simultaneously, comparisons were made between the Arlington time signals and the clocks at Ottawa and Emily.



Geodetic Survey of Canada. Astronomical Transit, Cooke No. 2.

LATITUDE.

A primary latitude consists of observations on twenty to twenty-five pairs of stars on two or more nights. The astronomical transit used in time observations for longitude is converted into a zenith telescope by turning the micrometer eye piece through ninety degrees, and by fixing to one of the setting circles a good level. The stars are selected from Boss's "Preliminary General Catalogue of 6188 Stars for the Epoch 1900". This method of latitude known as Talcott's gives a result with a probable error not larger than $\pm 0 \cdot ''10$.

ASIMUTH.

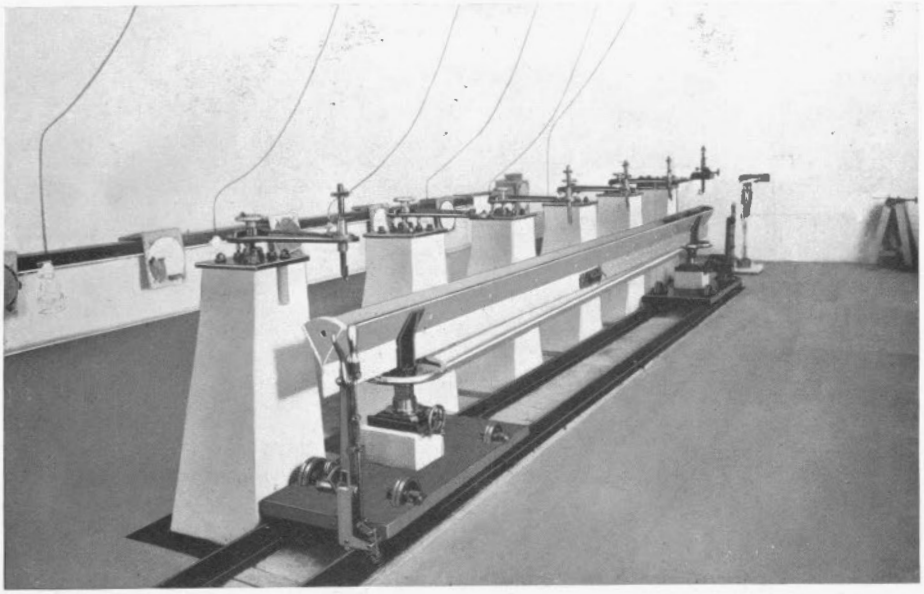
Three methods of azimuth observations have been used on the Geodetic Survey, viz., the direction method, the micrometer method, and a combination of the two called the micrometer-direction method. The last is the one now in use, and a brief description will not be out of place. The instrument is one of the Troughton & Sims two micrometer twelve inch altazimuth type. It is fitted with a micrometer eye piece, and a striding level.

The programme of observations is as follows: the instrument is centered over the geodetic point and levelled. The telescope is pointed on the mark, generally an electric or carbide lamp, and the micrometer wire set at some arbitrary reading is made to bisect the image of the light at the azimuth mark. The horizontal circle is clamped and its microscopes read, three sets of forward and backward readings being made. Five pointings are then made on the mark with the micrometer wire. The clamp on the horizontal circle is then loosened and the telescope pointed on Polaris, and the micrometer wire still set at the same arbitrary reading is brought on the image of the star. The horizontal circle is again read, five pointings of the micrometer wire are made on the star image noting the time of each; the striding level and altitude circle are read. The clamp on the horizontal circle is again loosened and the telescope turned through 180°, and similar sets of observations are taken on the star and mark.

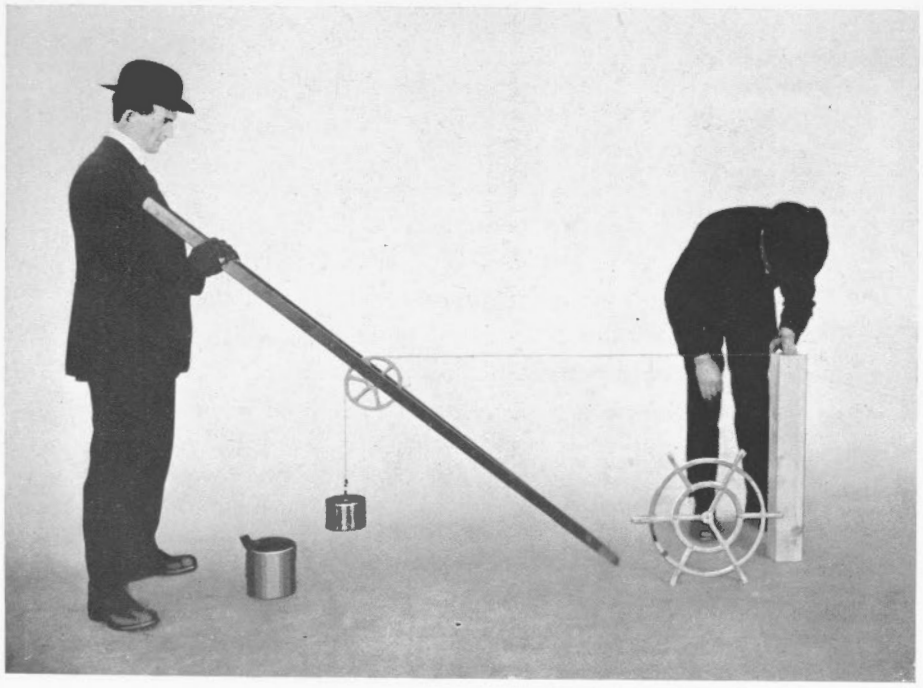
The effect of collimation is entirely eliminated in the mean of the two positions of the instrument, also the final result will be independent of any errors in the micrometer screw. A complete programme consists in observations in thirty-two positions of the horizontal circle. Such a set of observations gives a result with a probable error not greater than $\pm 0 \cdot ''15$. The chronometer errors are deduced from observations on the time stars in the vertical of Polaris.

DEVIATION OF THE VERTICAL.

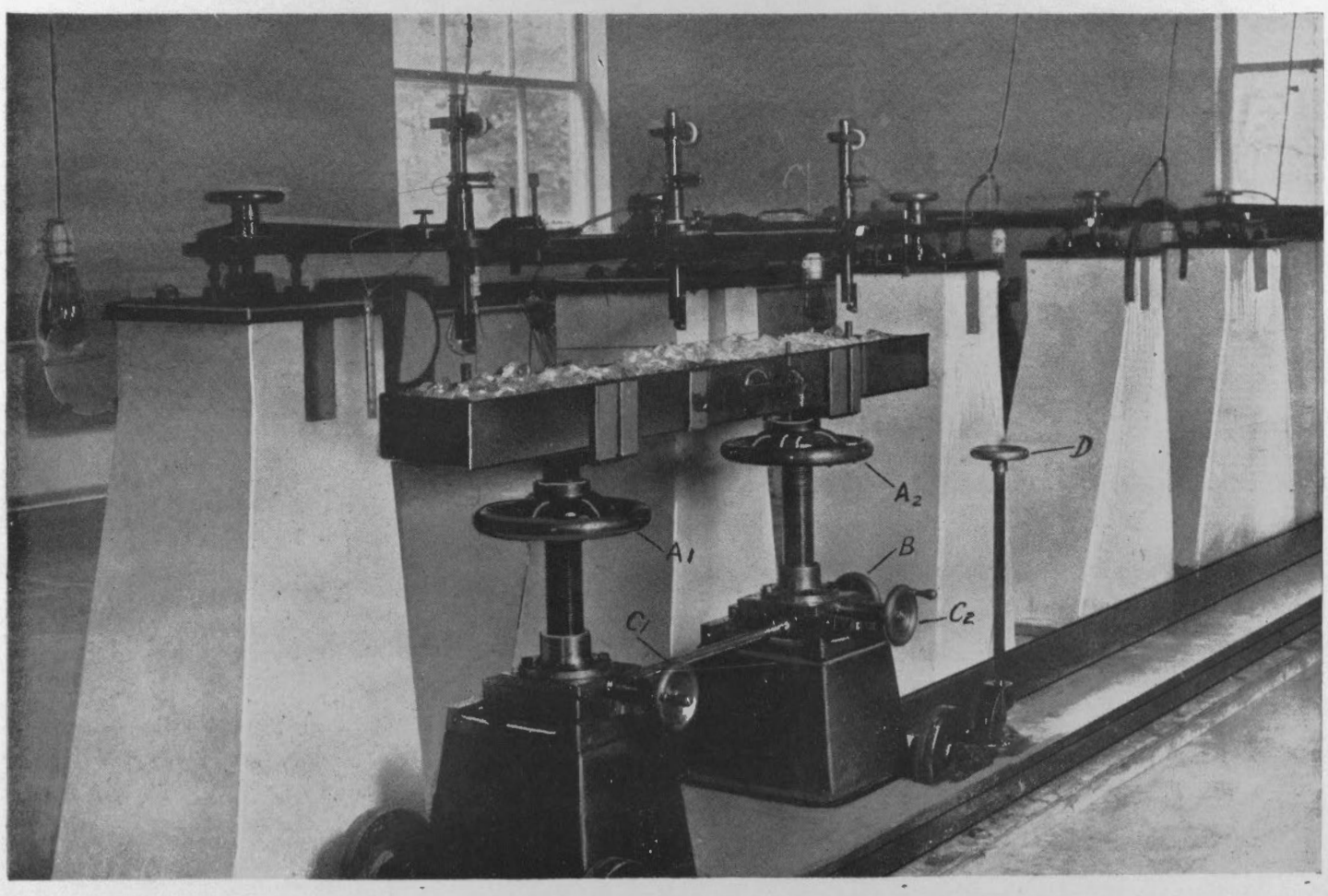
The deviations of the vertical obtained from comparisons of the astronomical longitudes and latitudes with the geodetic longitudes and latitudes are in some cases of considerable dimensions. The values of the deviations of the vertical at points along the shores of the St. Lawrence river have an increasing tendency towards the gulf. Tadoussac and Father Point, two stations nearly opposite one another across the river have deviations of nearly equal magnitudes but of opposite signs. At Cap-Chat the vertical is deflected towards the north and east nearly thirteen seconds of arc, while at West Base on Anticosti



In the Standardizing Building at Ottawa, showing the 5-metre Base at the north end of the Comparator, with the Trough holding the 5-metre Steel Bar and the Standard 1-metre nickel bar.



Base Line Measurement, showing Straining Bar and Weight for Applying Tension to the Tape during Measurement; also showing the Tape Reel.



Standards Building. Separate car carrying ice laden metre trough and metre bar.

island the deviation is small in a north and south direction and about six seconds in an east and west direction. The study of this problem in Canada is one that will be of great scientific interest to all interested in the question of Isostasy.

Base Lines and Standardization of Tapes.

Since the establishment of the Geodetic Survey there have been measured nine base lines for the control of lengths of the geodetic triangulation, eight since 1912. The location of these base lines their lengths and probable errors are shown in the table below.

The preparation and measurement of the base lines have all been made by a base line party. The observers who do the measuring in the field are the ones who standardize the tapes at the Standards Building of the Geodetic Survey of Canada. The methods employed are the same as those used on geodetic survey work in general and have been described in detail in the Report of the Superintendent of the Geodetic Survey of Canada for the year ending March 31, 1920. In the measurements, the base line is divided into kilometre lengths, and each kilometre is measured twice with two separate fifty metre tapes. Three tapes in all are employed being used in rotation two by two. The tapes are standardized before and after measuring each base by comparison with a five metre bar of tire steel in a solution of melting ice. This five metre bar is in turn determined from the standard nickel bar No. 10239 which in turn is frequently compared with two other metre bars No. 10241 and No. 10241A. Occasionally bar No. 10239 is compared with the standard metre bar of the United States Bureau of Standards.

Base Line Year	Mean Lat. and Long. of Base lines	Length in metres	Prob. Error in mm.
Côteau	Lat. 45° 15′	12536·4075	±5·138
1909	Long. 74° 16′		
Belleville	Lat. 44° 10′	13449·5539	±4·643
1913	Long. 77° 28′		
Delta	Lat. 49° 04′	12258·5500	±2·049
1914	Long. 122° 58′		
Stayner	Lat. 44° 25′	13849·5702	±1·980
1915	Long. 80° 04′		
Ekfrid	Lat. 42° 50′	14484·5428	±2·550
1915	Long. 81° 38′		
L'Islet	Lat. 47° 14′	12801·9726	±2·332
1917	Long. 70° 12′		
Westmoreland	Lat. 45° 56′	9399·9816	±2·827
1917	Long. 64° 13′		
Fort Rupert	Lat. 50° 40′	9547·2141	±1·924
1919	Long. 127° 35′		
Anticosti Island	Lat. 49° 52′	12373·2835	±1·462
1921	Long. 64° 10′		

Precise Traverse.

During the summer of 1921 a precise traverse was made of a section in the Niagara district between Townsend and Hamilton triangulation stations. The objects were primarily to determine if it is possible to carry the geographic positions of points through short lines by direction measurement of length and angles which would justify its use in connection with primary triangulation; and secondly to establish and ascertain the geographic positions of various points in order to control the land and lake surveys in a certain part of Ontario which had not the necessary control by primary triangulation.

The plan followed in the prosecution if this survey was to have two separate lines, designated as Traverse and Azimuth lines. The traverse line was surveyed in the usual manner measuring carefully the lengths and angles, and the azimuth line was used to carry the azimuth from Townsend to Hamilton providing a check at each azimuth station on the azimuth as carried through the traverse lines.

The total length of line measured is approximately seventy-five miles. The lengths were measured with a fifty metre invar tape on the flat; the traverse angles were measured with a six and a quarter inch Berger theodolite, and the azimuth with a twelve inch Kern theodolite. A party of four men in a sesaon of five months were able to measure these seventy-five miles of line, carefully checking all measurements to occupy the forty-four azimuth stations and one hundred and forty traverse stations involving the measuring of two hundred and fifty angles, besides computing in the field the co-ordinates of the stations.

Geodetic Control for City Maps.

Canadian cities are at present feeling the need of accurate, large scale city maps, and the Geodetic Survey of Canada is supplying them with geodetic control—triangulation, precise levels and precise traverses.

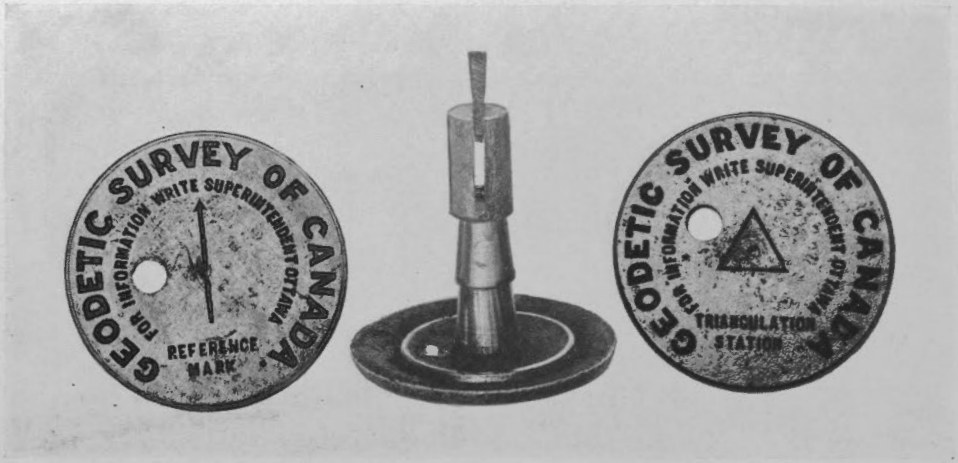
Triangulation nets have been surveyed for the cities of Halifax, St. John, Quebec, Montreal, Toronto, London, Vancouver and New Westminster, the accuracy desired being 1/100,000. The city net is connected with the nearest primary stations in the vicinity. The stations for control of the traverse net in the cities of London and Toronto are located about one mile apart, along the main traverse lines.

Precise level nets have been surveyed for the cities of Quebec, Montreal, London, Hamilton, Vancouver and New Westminster. These nets consist of a line of levels, based upon the precise level net of Canada, run around the outskirts of the city, closing upon itself, with cross lines, about a half mile apart, starting from and closing on the circuit bench-marks. Bench-marks are placed at about 1,600 feet intervals. Secondary levels are run over the traverse lines, establishing the elevation of traverse stations and such extra bench-marks as are needed.

Traverse nets have been surveyed for the cities of Toronto and London. The traverse work in Toronto consists of a few special lines, but the work in London, Ont., consists of a complete net, which establishes a station on one corner of every street intersection, marked

Clearing the Fort Rupert Base line—Using Spring Boards to get the height where tree is small enough to use cross-cut saws.

Using Spring Boards in sawing large cedar trees on Fort Rupert Base line, Vancouver Island.



Triangulation Station and Reference Mark Tablets.

These tablets are leaded into solid rock or are set in concrete monuments to mark, and reference triangulation stations. The wedge spreads the embedded end of the shank when the tablet is driven down thus adding to its solidity. The hole in the top of the tablet allows the melted lead to enter and fill the space around the shank, to hold it in its place.

by a copper bolt cemented in the concrete sidewalk. Special instruments have been designed and used for the London traverses; a "tape setter" to enable an accurate and steady setting to be made of the zero graduation of the tape over the mark; a traverse target plumbed by three levelling screws and two cross level vials; and an instrument to take the place of the plumb bob, so that an accurate setting of the transit can be made over the station mark in the highest wind. These instruments are described in the Superintendent's Annual Report for 1922.

Adjustment of Observations.

In the adjustment of both triangulation and level nets the following principles have guided the practice in the Geodetic Survey of Canada:

1. The adjutsment of as large systems as is economically and physically possible, in this manner applying the condition

$$\Sigma pv^2 = \text{a minimum}$$

to as many observations as possible.

2. The establishment of the precisions of functions, where these functions are conditioned by *all* of the observations.

3. Devising new theory for improving methods of adjustment and related problems.

4. Analysis of accumulative errors to determine where the accuracy of nets is failing. Such analyses demand the insertion of new base lines or Laplace stations in triangulation and the introduction of new cross circuit lines in level nets.

TRIANGULATION ADJUSTMENTS.

Since 1912 a number of triangulation nets have been adjusted:—

1. A net embracing the eastern part of Ontario and western part of Quebec. This was solved by the co-ordinate method, using as observational equations the equations as outlined by Dr. Helmert in his book Höhere Geodäsie, Vol. I, p. 282. Two base lines and four Laplace conditions entered into this adjustment and the adjustment was made according to the plan indicated in Helmert's Ausgleichungsrechnung, p. 264. Precisions of certain sides and certain directions were found according to the scheme outlined on page 265 of the same work.

2. A net embracing central and western Ontario, having two bases and two Laplace stations. The adjustment was made by the method of conditions.

3. A net embracing the southeastern part of the province of Quebec, having one base and one Laplace point, was adjusted by the method of conditions.

4. A net embracing the course of the St. Lawrence river and gulf, having one base and two Laplace points. This is being done by a new method—the differential adjustment by conditions.

5. Two nets embracing the bay of Fundy and Cape Breton island. The former has one base and two Laplace points and the latter one base and one Laplace point. Both were adjusted by the method of conditions.

6. A net embracing the coastal outline of British Columbia, having two bases and two Laplace points. This is being adjusted by the new method of differential adjustment by conditions.

In the above nets additional control was present in the fixed lines of previously adjusted nets, to which these nets were joined.

LEVELLING ADJUSTMENTS.

The net of precise levels extends over the whole of Canada. After the Orthometric Corrections had been applied to the observations, a new differential adjustment was applied.

By this differential adjustment, the whole net was first adjusted to tidal stations on the Atlantic seaboard. Differential values, forming a second adjustment, were given to the first adjustment to allow for the influence of the Pacific ocean tidal stations. A third differential adjustment additive to the above two, is being formed to allow for the influence of the United States points along the International boundary, which are to be held as fixed.

In each of the above adjustments the total correction is the same if as the condition

$$\Sigma pv^2 = \text{a minimum}$$

had been obeyed for all the observations, but with this extra advantage, that each differential adjustment shows the effect of the new material on the old.

Each year's observations will be adjusted, giving new differential adjustments, and

showing how such new material affects the old. The whole effect is the same as if all had been adjusted simultaneously.

In both the triangulation and level net adjustments, precisions of functions have been inserted. By the differential adjustment the variation of these precisions is being noted, thus showing how new observations affect the precisions of old functions.

In all cases the precisions have been evaluated in connection with all the observations, as it was felt that the precision of a function, depending upon a single chain of triangles alone was not necessarily near the truth. The influence of the whole network must be considered.

New Theory Developed.

THE EVALUATION OF GEODETIC CO-ORDINATES.

By this theory products of tan x, tan y, ... etc., are evaluated as x, y, ... etc., by the use of tables showing the value of log tan x − log x and log sin x − log x.

A relation between the spheroid and the sphere of radius N being known, where the longitude is the same in both cases, it follows that geometrical proofs on the sphere can be easily transferred to spheroidal proofs. Also by the use of right angled triangles on the sphere, rapidly, converging series in even or in odd powers of the variable $\frac{s}{N}$ take place.

By employing the above considerations the calculation of geodetic co-ordinates is very much shortened, especially for longer lines thereby conducing to accuracy.

THE ADJUSTMENT OF OBSERVATIONS BY SUCCESSIVE DIFFERENTIAL SOLUTIONS.

In this adjustment the method of conditions is used. Each successive adjustment gives additive corrections to the correlates and to the v's of the adjustment. The resulting v is the same as if all the observations had been adjusted simultaneously.

The advantage of this adjustment is two-fold—

First all the preceding adjusted work is preserved and the effect of the new is noted This differential effect is noted not only for the v's but also for the precision of the adjustments;

Second: by rearrangement of the conditions, a large net can be broken up into parts, each part adjusted by itself and the differential effect due to the advent of the conditions binding the several piece nets, noted.

DERIVATION OF A THEORY FOR TRANSFORMING POLAR DISTANCES AND AZIMUTHS EVALUATED ON THE PLANE, TO POLAR DISTANCES AND AZIMUTHS ON THE ELLIPSOID.

The need for this arose from the use of precise traverses. These precise traverses were composed of many measured distances, and the included angles. Generally these distances are short and very numerous. The beginning and ending of a precise traverse are generally previously fixed primary geodetic points.

Hence, in the reduction, the natural tendency is to evaluate the traverse by latitudes and departures, *i.e.* as if the traverse were actually measured on a plane.

Obviously the final polar distance and azimuth on the plane are not exact. To correct this has been the object of the theory.

This theory is an extended application of Lgendre's Theorem, the corrections to the plane latitudes and departures being functions of the spherical excesses.

A NEW PRESENTATION OF GEODETIC THEORY.

A system of geodesy based upon the geodetic line S and the equation of the ellipsoid

$$x^2 + y^2 + z^2 - 2zN + \delta (x \cos \varphi - z \sin \varphi)^2 = 0$$

has been evolved and, it is believed, has been of great assistance in the higher problems of geodesy.

STUDIES ON EFFECT OF ACCUMULATIVE ERRORS.

The effect of accumulative error has been studied in two ways:—

1. By finding the precision of functions after the adjustment has taken place. This is the most accurate method known, but unfortunately it is very slow.

2. By deducing approximate precision results through a selected chain of triangles. This is obviously much quicker, but at the same time far less accurate.

This is the method that is generally used for the location of base lines, but this method deals principally with the shape of the triangles in the selected chain and cannot obviously deal with the quality of the individual observations in the chain, to say nothing of not dealing with the quality of the observations of the remaining part of the net.

The selection of Laplace points is more difficult, as the error in azimuth of the geodetic triangulation cannot be known until the geodetic azimuth is first determined. This is a very slow process and does not conduce to the laying down of Laplace points at the time the triangulation is being laid down or observed.

It is felt that the derivation of the theory for transforming plane polar distances and azimuths to those of the ellipsoid will solve, for a chain of triangles, the approximate location of Laplace points.

PUBLICATIONS.

It has been the practice of this Survey to issue publications containing data made available by completed operations, for the use of engineers, surveyors and surveying branches of the Federal and Provincial Governments. Geodetic and Topographical methods of field and office work are also included. The publications are as follows:—

Publication No. 1—Precise Levelling—Certain lines in Quebec, Ontario and British Columbia.

Publication No. 2—Adjustment of Geodetic Triangulation in the Provinces of Ontario and Quebec.

Publication No. 3—Determination of the Lengths of Invar Base Line Tapes from Standard Nickel Bar No. 10239.

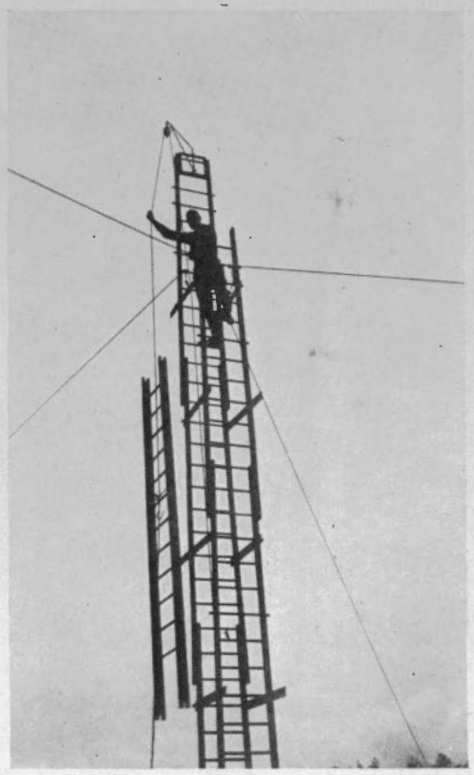
Publication No. 4—Precise Levelling—Certain Lines in Ontario and Quebec.

Publication No. 5—Field Instructions to Geodetic Engineers in charge of Direction Measurement on Primary Triangulation.

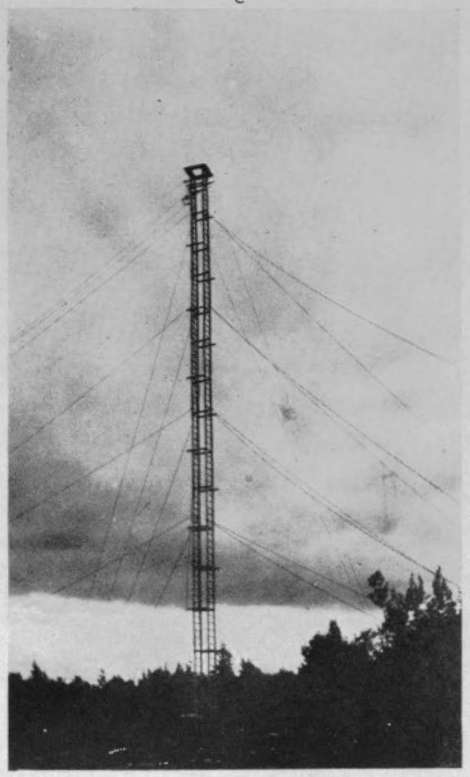
Appendix No. 1 of Publication No. 5—Instructions to Lightkeepers on Primary Triangulation.

Publication No. 6—Precise Levelling—Certain Lines in Manitoba and Saskatchewan.
Publication No. 7—Geodetic Position Evaluation.
Publication No. 8—Field Instructions for Precise Levelling.
Publication No. 9—The Making of Topographical Maps of Cities and Towns, the First Step in Town Planning.
Annual Report of the Superintendent of the Geodetic Survey of Canada for the Fiscal year ending March 31, 1918.
Annual Report of the Superintendent of the Geodetic Survey of Canada for the Fiscal year ending March 31, 1919.
Annual Report of the Superintendent of the Geodetic Survey of Canada for the Fiscal year ending March 31, 1920.
Annual Report of the Superintendent of the Geodetic Survey of Canada for the Fiscal year ending March 31, 1921.
Annual Report of the Superintendent of the Geodetic Survey of Canada for the Fiscal year ending March 31, 1922.

Copies of the above publications may be obtained by applying to the Superintendent of the Geodetic Survey of Canada. A permanent mailing list is maintained by means of notification cards. No charge is made.

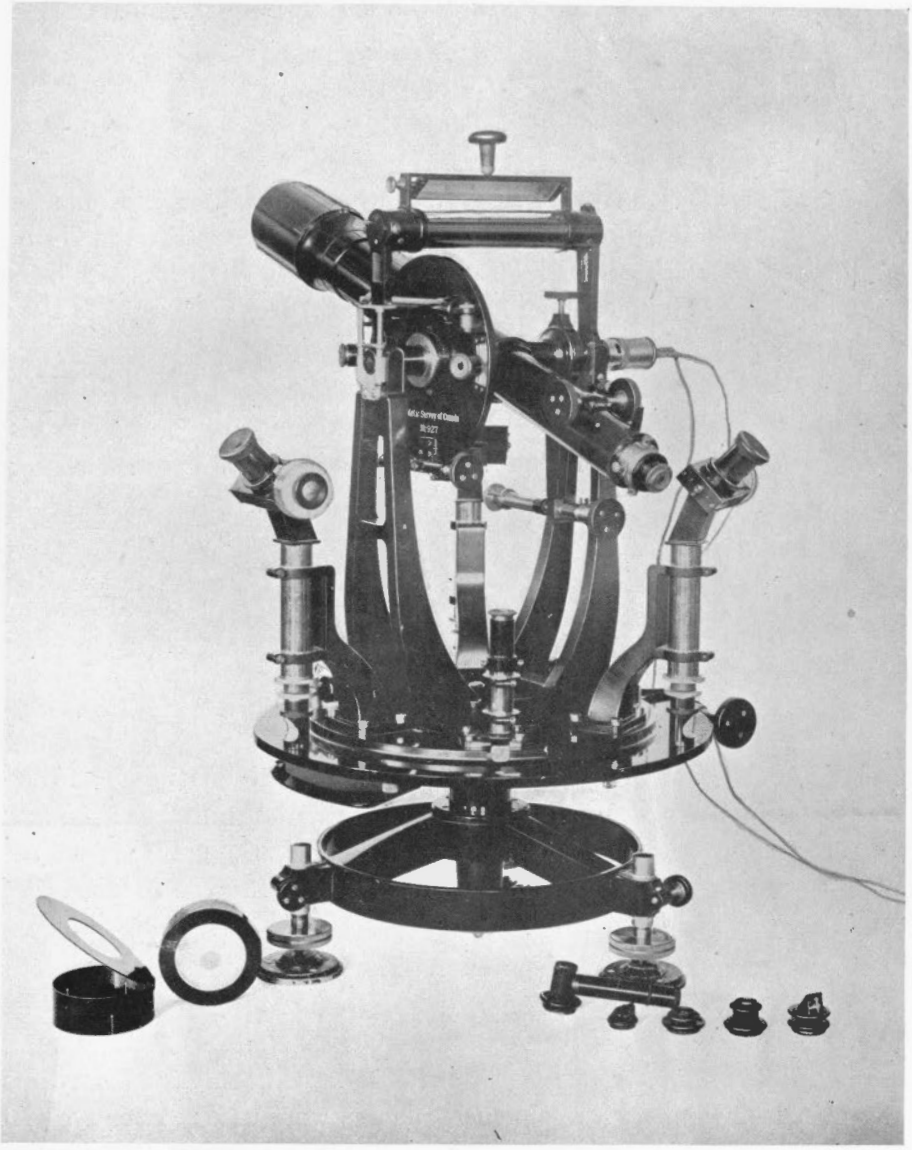


(*a*) In course of erection.



(*b*) Complete, 78 feet high.

Portable Tower used for Reconnaissance, Geodetic Survey of Canada, Modeled after the Dismountable Observation Ladder of the Geographic Service of the French Army.



12-inch Kern 3-Micrometer Theodolite for measuring Horizontal Angles on Primary Triangulation.

GEODETIC INSTRUMENTS.

Twelve Inch Theodolites.

Since 1912 a new type of 12-inch (30 cm.) theodolite has been obtained for the measurement of horizontal angles on the primary triangulation. This type of theodolite was manufactured to the specifications of this Survey, and two special features entered into its design. The weight was considerably lightened and the instrument was so designed as to be as compact as possible.

Theodolites in previous use were heavy, the box containing the alidade and base weighing from 120 to 150 lbs. (55 to 68 kg.). In the new theodolite the instrument and cases were lightened as much as possible, the weight of alidade in its box being 63½ lbs. (28·8 kg.), the telescope in its box being 21½ lbs. (9·8 kg.) and the weight of the theodolite complete without cases being 35 lbs. (15·9 kg.).

Compactness was secured by placing the micrometer microscopes vertical, a prism at the upper end of each of the three microscopes permitting convenient vision to be obtained. A photograph of this theodolite is shown on page 27.

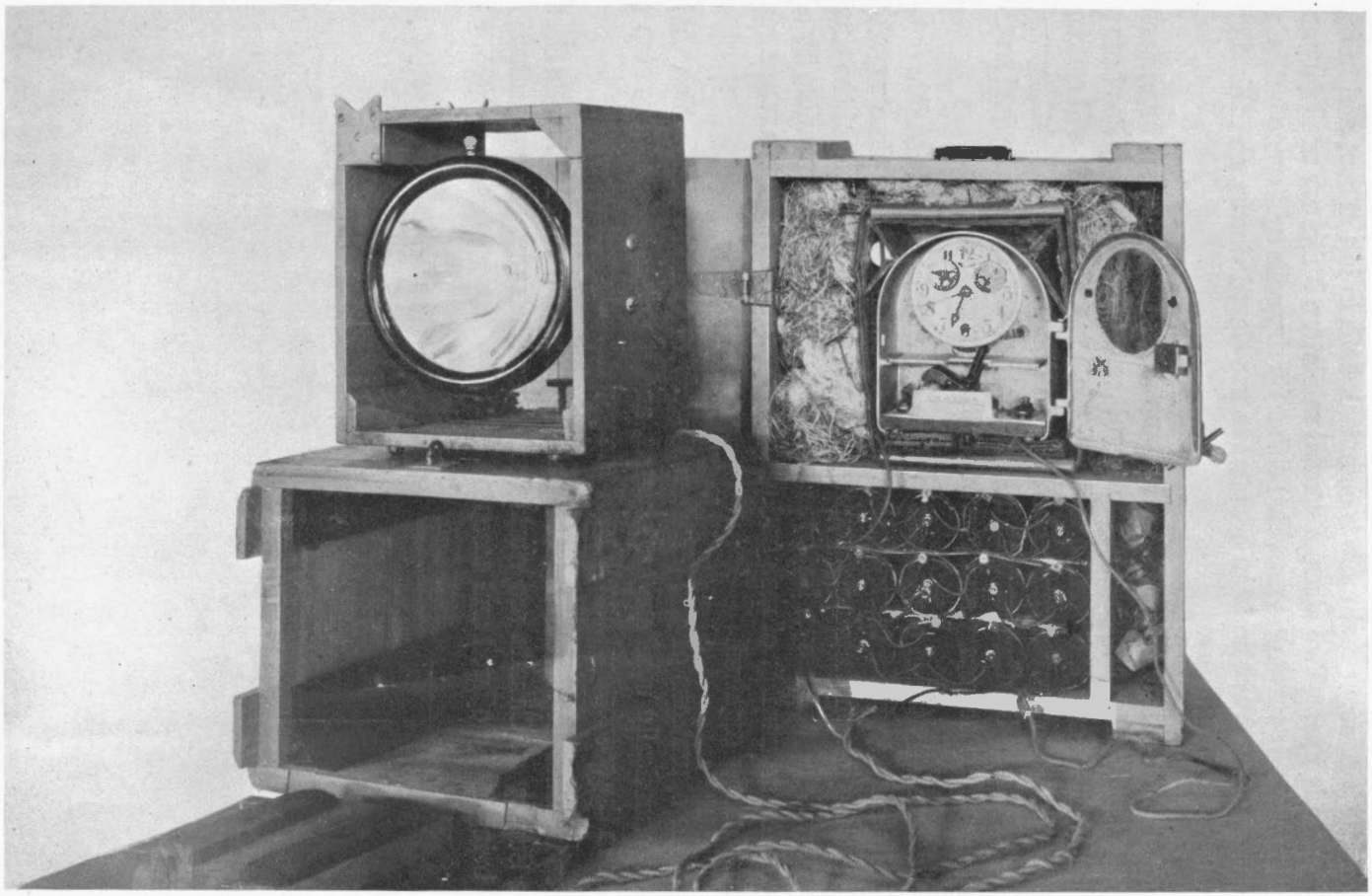
Inaccessibility of many triangulation stations and increasing cost of manual labour were reasons why the minimum of weight was specified. It is the consensus of opinion in Canada that the greater stability of the heavier type of theodolite does not sensibly increase the accuracy of angular measurements.

Electric Signal Lamps and Automatic Time Switches.

The Geodetic Survey has been able to show a substantial economy in the operation of one class of its parties by the introduction of automatic time switches in connection with electric signal lamps on triangulation parties. Where this apparatus can be used the number of employees on the angular measurement parties may be reduced by from 4 to 7 men with a corresponding saving.

The angular measurements of the triangulation of the Geodetic Survey of Canada are made at night, as this practice proves more economical and accurate than making them in the day time. Instead of pointing on signals, as one may in daytime, it is necessary to point on lights, and various types of lights have been used from time to time. First railway signal oil lamps with condensing lenses were used; later acetylene lamps, somewhat similar to the old style automobile headlight—but much larger—were found to be a great improvement. Each lamp is tended by one, or in some districts two, lightkeepers, from 5 to 8 lamps being necessary for each party.

As the triangulation lines are long—from 10 to 40 or 100 miles—and as haze or fog often makes it impossible to see these distances, it has been the constant aim to increase the strength of the lamps, and, hence, increase the number of nights on which observations can be made.



Electric signal Lamp with Automatic Time Switch.
This equipment automatically turns the electric lamp on and off at predetermined hours, and eliminates lightkeepers where transportation is quick and the stations fairly close together (see text).

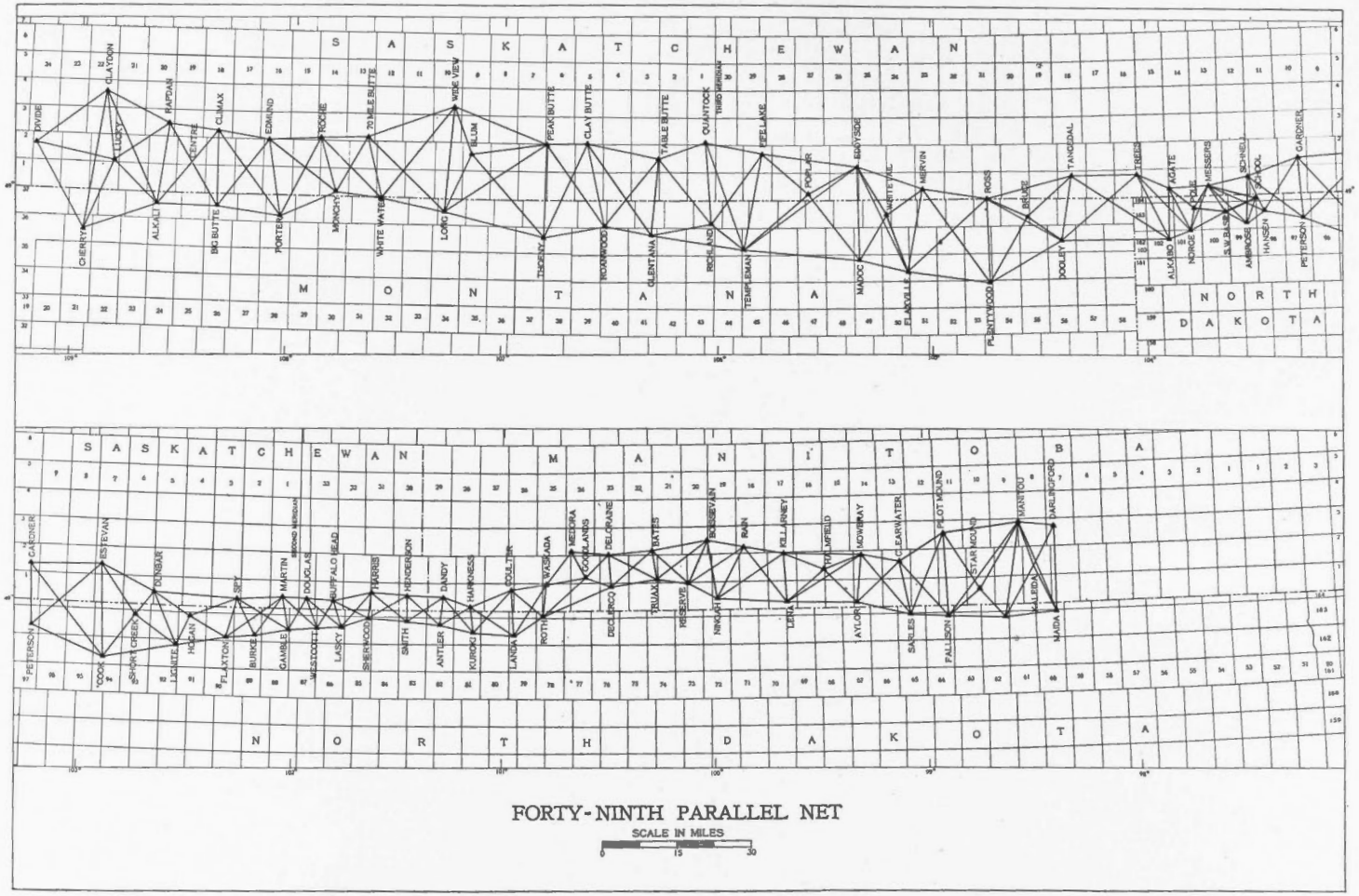
In 1920 electric lamps were introduced. Automobile headlights were specially mounted and proved much stronger and more economical, both in initial cost and in operation, than the acetylene lamps. Two sizes of special miniature bulbs are used (depending on the length of line), while current is provided either by dry cells or storage batteries. The old style acetylene lamp has also been adapted to use electric bulbs, and this change has greatly increased its efficiency.

The latest improvement to the electric lamp makes possible an important saving in operation. A time switch is placed in the circuit and, when the lamp has been properly lined, the clock wound and the "on" and "off" dials set, the switch will automatically turn the light on and off at pre-arranged hours. In this way several lightkeepers may be dispensed with, only one lightkeeper with a light motor truck being attached to the party to move the lights when necessary and to wind the clocks once a week.

It is to be noted that this equipment will, in general, be found feasible only where transportation is easy and the triangulation stations comparatively close together. Its use would be limited in a mountainous country for example, on account of the time which would be lost moving all the lamps, but even in such cases a saving is possible by employing only the minimum number of men and using the automatic switches where more men would be occasionally required.

Several other operations of the Geodetic Survey of Canada with which this equipment can be economically used are anticipated, and it is felt that a large step forward has been made in the economical handling of triangulation operations.

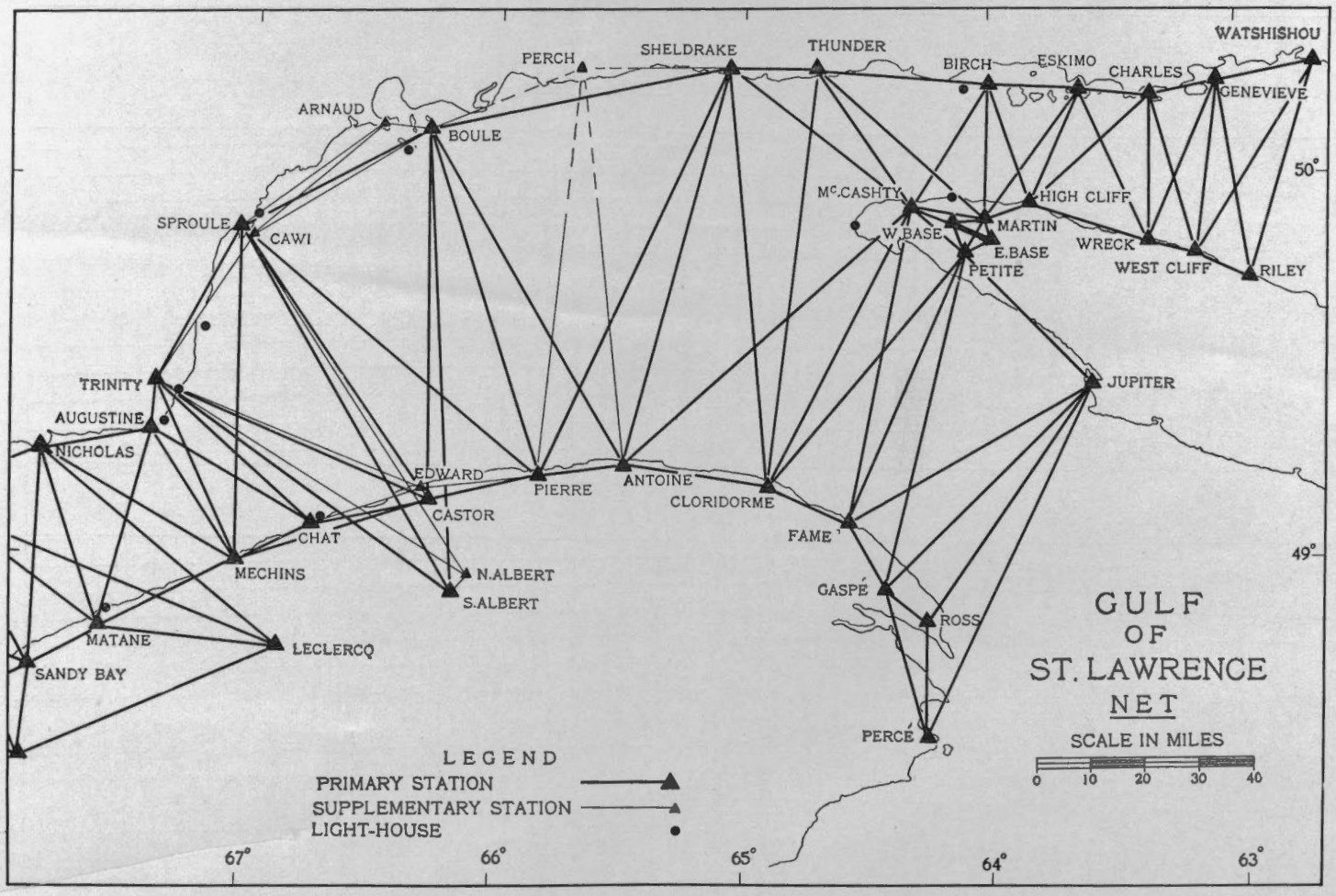
In this, as in other improvements, the United States Coast and Geodetic Survey and the Geodetic Survey of Canada are working in close harmony, the suggestions of each organization being freely offered and accepted.



FORTY-NINTH PARALLEL NET

SCALE IN MILES

0 15 30


WATSHISHOU
PERCH
SHELDRAKE
THUNDER
BIRCH
ESKIMO
CHARLES
GENEVIEVE
ARNAUD
BOULE
50°
McCASHTY
HIGH CLIFF
SPROULE
CAWI
W.BASE
MARTIN
E.BASE
PETITE
WRECK
WEST CLIFF
RILEY
TRINITY
JUPITER
AUGUSTINE
NICHOLAS
EDWARD
PIERRE
ANTOINE
CLORIDORME
CASTOR
CHAT
FAME
49°
MECHINS
N.ALBERT
S.ALBERT
GASPÉ
ROSS
MATANE
LECLERCQ
SANDY BAY
PERCÉ
GULF
OF
ST. LAWRENCE
NET
SCALE IN MILES
0 10 20 30 40
LEGEND
PRIMARY STATION
SUPPLEMENTARY STATION
LIGHT-HOUSE
67°
66°
65°
64°
63°