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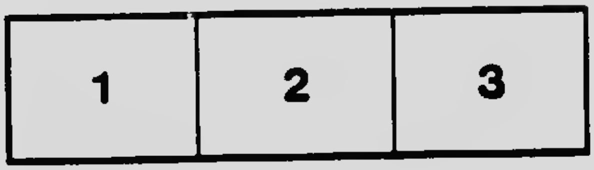

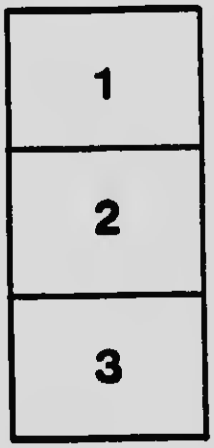

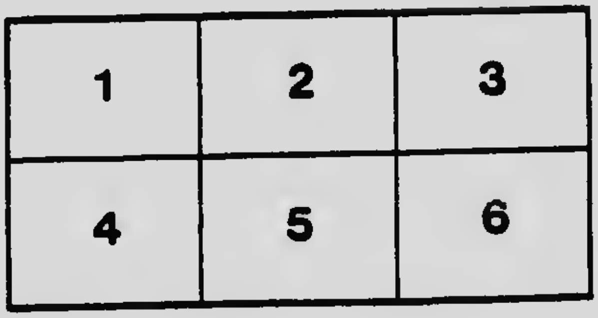

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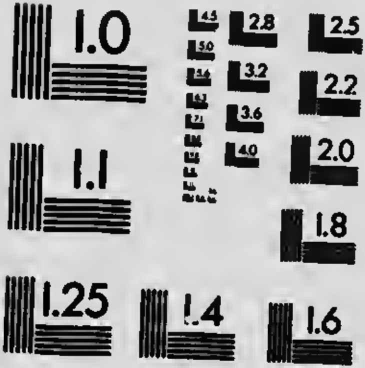

Biggar, [illegible] A.

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THE GEODETIC SURVEY OF CANADA

BY

CHARLES A. BIGGAR
DOMINION OBSERVATORY, OTTAWA

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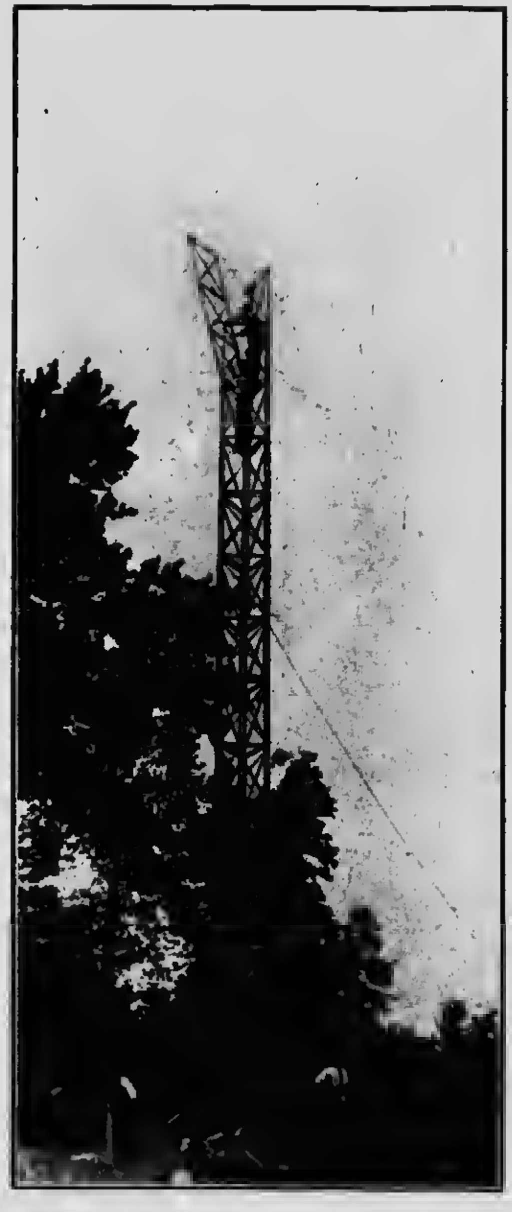

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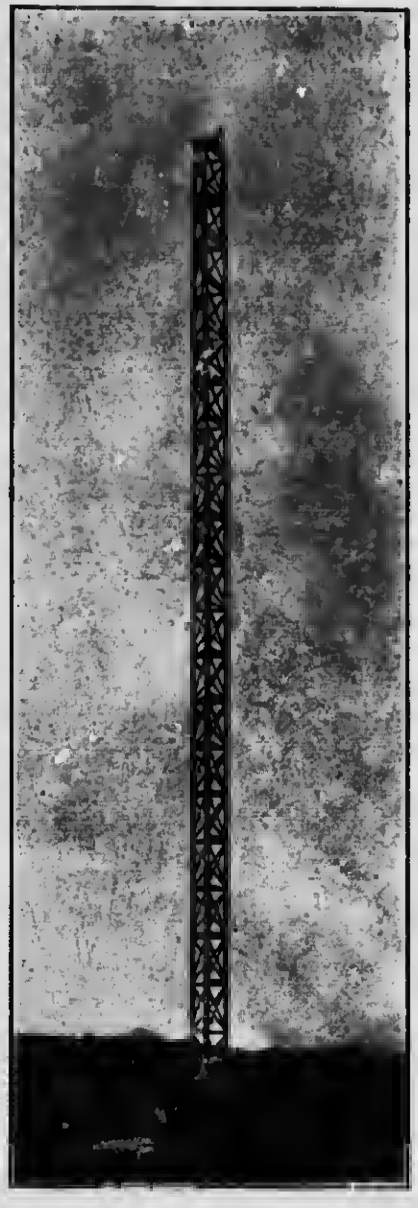

Complete

PORTABLE RECONNAISANCE TOWER, CANADIAN GEODETIC SURVEY

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THE GEODETIC SURVEY OF CANADA*

By Charles A. Bigger

GEODETIC SURVEYS have been in progress in other countries for more than a century; an historical sketch of them is not within the scope of this paper, which is intended to describe the Canadian Survey, which has been spread over Canada in isolated sections from the Atlantic to the Pacific Ocean.

The visible signs of the existence and extension of the work consist in what may be termed skeleton towers, which in a general way are similar to other structures of well known utility, such as wind-pumps or deep-well boring apparatus. The material used in their construction is wood varying in size from two by four to eight by eight inches. These skeleton towers are observing stations; on account of the necessity for intervisibility, they are erected on the highest ground within a radius of many miles. Thus they are seen from the public highways projected against the sky, and as they are scattered over the most thickly populated portions of Canada, the interest they have aroused is wide spread and insistent, indicating a universal desire to know the story of the Survey.

As viewed against this most effective of all back-grounds, the sky, the observing towers present outlines which are essentially different from any of the structures heretofore familiar to the public. There is no central shaft and there are two structures -- one within the other — and the outlines of these structures are curved instead of straight. The number and variety of questions that have been asked with reference to the reason for their sudden and unaccountable appearance in the midst of hitherto peaceful and law-abiding communities are more easily

* Read before the R.A.S.C. at Ottawa, October 10, 1912.

imagined than answered. The words peaceful and law abiding, are used advisedly; in one quiet hamlet they were supposed to mark concealed magazines for stores, explosives; in another they were said to have been erected for the use of political orators with megaphones, that the ensuing general election might possess novel features, and incidentally tend to the glory and perpetuation of the Government of the day. The Press throughout the country has also contributed its quota to the general expression of interest; but as a rule, the tone of press comments has been derisive.

It must be confessed that the task of endeavoring to make the story of the Geodetic Survey interesting, has been assumed with many misgivings. Nor is it to be expected that the huge interrogation mark resting upon the country at large can be straightened out by a single narrative, but it is hoped that a more sympathetic understanding may be aroused, so that in future the Departmental reports on this subject may receive more than casual notice; and further, that the Survey may take its place beside other Public Works of accepted utility. There is another phase to Geodetic Surveys which is of absorbing interest to the scientific world, *viz.*, the necessity of an accurate knowledge of the exact size and figure of the earth. All astronomical computations, having for their object the determination of celestial distance, are based upon this knowledge — the accuracy of the determination of the movement of the heavenly bodies — the map of the heavens — depends upon the results of Geodetic Surveys based upon the science of Geodesy.

The original settlement, and establishment of homes in new countries is made possible by surveys defining the limits of the homesteads. Villages, towns and cities make their appearance in the wake of surveys, and thus surveys may claim to be the beginning of substantial progress in all countries. The development of public works such as canals, railways, roads and bridges has its origin in accurate surveys.

In Canada a systematic plan of survey was adopted during the last decade of the eighteenth century. In 1794 instructions were issued to Deputy-Surveyor Stegman to survey the boundaries of certain townships in the vicinity of Ottawa, and to place monuments marking the limits of lots, fronting upon the Ottawa and Rideau Rivers, having an approximate area of two hundred acres each. The remaining portions of these townships were subsequently sub-divided by other surveyors; the maps and field notes of these surveys, and surveys of a similar nature all over Eastern Canada are the only official records of the size and form of our country. The measure of the accuracy of the surveys referred to is within the knowledge of the writer. In one locality near Ottawa a tract of land three-eighths of a mile wide, not included in the township surveys, was discovered quite recently, and in another township quite near the tract referred to, another fertile belt one-eighth of a mile wide has never been discovered officially. The existing maps of the older portions of Canada are compilations of surveys similar to those mentioned above. The expert knowledge and ingenuity of geographers have been taxed to their utmost in arranging by torsion the data at their disposal, so that many disturbing discrepancies might be reconciled as far as possible.

Since the formation of a permanent staff of astronomers in Canada the latitude and longitude of many points have been established by astronomical observations, these being subject to influences introducing an element of uncertainty which science cannot cope with except through the medium of a Geodetic Survey. For the purpose of maps of the scale commonly employed the observations referred to have been invaluable in view of the fact that the uncertainty of such observations is not of sufficient magnitude to be appreciable on maps of small scale.

The development of the natural resources of Canada has far outstripped her progress in some branches of scientific work; the necessity for accurate detail maps of the surface of the country has long been felt. The data for placing the parallels of latitude and meridians of longitude in their true places with reference to available surveys of the townships and lots, could be secured in no other way than by a Geodetic Survey.

All geodetic stations are connected by survey to the nearest township lot corner, in this way making the Geodetic Survey a basis for accurate skeleton maps on which may be placed the contours of the surface and all the geographical and physical information necessary to form maps containing information to aid materially in the commercial and strategical development of Canada. The accuracy of all future surveys for public works such as canals or railways or any other work requiring accurate surveys, may be checked absolutely by referring them to the nearest geodetic station as the work of such surveys progresses.

The foregoing may be considered as a general statement of the scope and object of the Geodetic Survey of Canada; the story of the work itself may be found more interesting.

The physical features of that portion of Canada extending from the westerly boundary of the State of Maine to the Detroit River and Lake Huron — the section to which the energies of the Geodetic Survey have been more particularly directed, may be briefly described as follows.

In the Province of Quebec, from the State of Maine to a line drawn due south from Rigaud, forty miles west of Montreal, the surface in the easterly section is rolling and hilly and in some sections mountainous, flattening out as the westerly limit mentioned is approached, but with isolated mountains rising more or less abruptly from the comparatively level plains. This district was found to be especially favorable for geodetic work: there are triangles in this section having sides eighty miles long.

From Rigaud, westerly throughout the remainder of the Province of Quebec and through southern and south-western Ontario to the Detroit River and Lake Huron, conditions were encountered that were most discouraging, and taxed to the utmost the skill and patience of those entrusted with the preliminary work of selecting the stations for the purpose of the survey. For long stretches the surface is slightly undulating with occasional stony ridges, usually old sea beaches, of no decided elevation above the surrounding country. Between Lake Ontario, Lake Huron and Georgian Bay, the general surface gradually ascends by means of extensive transverse ridges which are themselves broken up into rolling and hilly surfaces until an elevation of seventeen hundred feet above sea level is attained in the vicinity of Dundalk.

The work of the survey is divided into the following branches, proceeding in the order noted; reconnaissance, station building, observing and computing. The astronomical observations and the measuring of the base lines — the other branches of the work — may be introduced when deemed best for the progress of the survey.

RECONNAISSANCE

In the month of June, 1905, the work of the Geodetic Survey was commenced at Kingsmere, a short distance west of Chelsea, in the Province of Quebec. One of the three high elevations just north of Kingsmere Lake was visited on that date by the writer, and a careful study of the surrounding country made, having in view the selection of stations most suitable for the purpose of the survey.

The survey is spread over the country trigonometrically — in other words by means of triangles — starting from a measured base, having the angles of the triangles measured, and their sides computed by the aid of trigonometry, which may be briefly stated as the science of determining — in the case of the Geodetic Survey — the lengths of the two unknown sides of a triangle when one side and the angles have been measured. The triangles selected are combined to form four, five, six and even seven sided figures for more precise computation of distance. The angles of the triangles are measured by instruments of precision called theodolites, which are constructed with the greatest possible accuracy. When a theodolite is placed at one of the angular points of a triangles, it is essential that all the other angular points of all the triangle to which this point is common, are visible; it is also essential that all the angles of primary importance to the survey shall be more than thirty degrees. The above requirements must be fulfilled in the selection of the angular points — or stations — when the reconnaissance and preliminary survey is made.

In order that the intervisibility referred to may be secured it is necessary to erect skeleton towers on which the theodolite is mounted, a sufficient height above the ground to command the other stations to be observed. The determination of the heights of these towers is one of the duties of the officials conducting the reconnaissance survey.

Base lines are measured at intervals throughout the survey, and as these base lines are sides of triangles, forming part of the main chain of the survey — and all the angles of the triangles are measured — the computation of the lengths of all the sides of the triangles between the bases, seems to be a comparatively simple problem. When the magnitude of the triangles involved is considered — some of the sides exceeeding eighty miles — elements are introduced which require most elaborate and exhaustive mathematical investigation.

Astronomical observations of latitude, longitude and azimuth are made at suitable stations, so that the geographical position of every station of the survey may be computed.

The selection of the angular points of the net-work of triangles is the beginning of the survey. Officials specially trained, and possessing instinctive knowledge of locality in its widest and most comprehensive sense are sent out to make an examination of the surface of the country to be covered. The highest points are visited, and from such points as are considered possible for stations, careful sketches of the horizon are made; the directions of all prominent elevations are referred to the astronomical meridian by means of observations on the the sun, or if the day is cloudy, to some known point located on the map used for this work. The surveyor's outfit for reconnaissance consists of a small theodolite with vertical circle and magnetic needle, a good three-inch compass, a telescope, field glass and a pair of climbers similar to those used by telephone employees.

Many of the stations occupied are timbered and the observations must, therefore, be made from trees, and the work is carried on all the year round. Mounting an instrument on the sawed off trunk of a tree fifty or sixty feet from the ground — clinging to the side of the tree with the aid of climbing irons and making an exhaustive study of the horizon in a temperature many degrees below zero -- with a wind: these conditions call for mental and physical qualities of no ordinary calibre. One assistant surveyor is allowed to each party. He records all observations and is usually selected on account of special qualifications for the work so that he may in time assume charge of a section of the reconnaissance survey.

At the close of the day, the stations occupied are marked on the map and lines radiating therefrom to other possible stations are plotted. As the work progresses the surveyor in charge becomes familiar in a general way with the trend of the culminating ridges -- sometimes called the grain of the country — and can begin the formation of triangles, quadrilaterals and polygons. He then encounters the many difficulties due to the scientific requirements of the work. Certain lines are found to pass over cities, which makes them subject to local heat waves and smoke. Other lines graze the sides of timbered ridges, exposing them to lateral refraction which causes serious errors in the measured angles. The work of re-adjusting the figures to avoid these unfavorable conditions is undertaken. Other difficulties arise unexpectedly -- perhaps one of the most important lines in a large figure is found to be closed, and another station or stations must be selected.

As the survey is extended and enlarged, the accumulation of obstacles and difficulties is most disheartening. The official in charge of the Geodetic Survey finds it necessary to visit these parties at intervals in order that these mountains of trouble may — to a certain extent -- be made to appear less formidable.

The success of the survey is largely dependent upon the thoroughness of reconnaissance; especially in the country covered in Canada where the selection of figures of fixed mathematical strength is impossible. There is no choice; it is a case of making the best possible use of the surface of a country which is not designed for Geodetic Surveys of ideal mathematial conditions. The applications of rules for determining strength of figures and limiting the field work to certain requirements based upon these rules would entail an expenditure similar to that of the construction of a railway from Calgary to Vancouver -- in a straight line. The economic assimilation of theoretical and practical requirements is essential to success -- perhaps to a greater extent in a Geodetic Survey than any other undertaking -- as the computations involved drift naturally and by most attractive routes into refinements which are infinitely beyond the possible precision of the measurements of the magnitudes involved.

The work of reconnaissance is now in progress in advance of the other branches of the survey. The experience of the Canadian Survey with respect to this section of geodetic work has presented no new features, when compared with similar work in other countries. Perhaps an exception may be made with reference to carrying on the work in winter. On account of the scarcity of prominent elevations, and the prevalence of timber, the winter season has been found most suitable for reconnaissance in Canada. The absence of leaves from the trees and the covering of snow on the hill tops are invaluable in disclosing the irregularities of the horizon.

The completion of reconnaissance is followed by the preparation of the stations for their occupation by the large theodolites. After this is accomplished, and before the theodolite is used, the reconnaissance party examines the lines, testing them for intervisibility. Should any of the lines be closed the obstruction is located by survey and, if possible, removed. Should the obstruction amount to "grounding" the line, the whole figure involved must be revised and made possible by the insertion of one or more additional points. Many of the lines cannot be tested before the observing towers are erected. In 1910 a portable tower was devised which has proved a great assistance. It is in sections, three by twelve feet, arranged for bolting together for the purpose of erection. Its form is triangular and its height eighty feet; eight wire cable guys are used to secure rigidity, and it has been exceedingly useful to the work.

STATION BUILDING

Following in the wake of the reconnaissance is a party of signal builders. Their work consists of the preparation of the stations for their occupation by the observing party. In the Province of Quebec and occasionally throughout Ontario, stations occur on mountain tops where no towers are necessary — except in special cases referred to subsequently. Such stations are marked by round copper bolts three quarters of an inch in diameter, the geodetic station being indicated by an eight-inch triangle cut in the rock around the bolt marking it. Three other bolts are placed in solid rock at convenient distances at the points of arrows, the shafts of which radiate from the station bolt. All the bolts are fastened into close fitting drill-holes so that their permanence is assured. The central bolt is stamped with a cross, the letters "G. S. C." and the year of location.

Stations in a hilly or undulating country cause more work in their preparation; skeleton towers from thirty to one hundred feet high become necessary in order that the other distant stations may be seen. These towers consist of a tripod surrounded by a scaffold to support the observer so that when a theodolite is mounted on the top of the tripod the observer may walk around his instrument without disturbing it.

The whole structure is designed and erected so as to obtain maximum rigidity with the minimum weight of timber, the latter varying in size from two by four to eight by eight inches according to the height of the tower. By renewing the footings, tightening the spikes and if necessary reinforcing the insides of the tripod legs, the efficiency of these towers can be maintained for a period of about ten years.

The construction of the towers is carried on by men especially adapted to the work; these men have continued with the survey from year to year since its inception. They are excellent rough carpenters, and, at least, one of them must know how to take and compute an astronomical observation at any time during the day, as the tower legs must be placed clear of all the lines to be observed. The foreman of the tower building party revises reconnaissance, examines lines for intervisibility, makes the necessary surveys for finding obstructions, removes them; is in fact an official whose work is most varied and constantly in demand.

One side of the tripod and two sides of the scaffold are framed on the ground. A single post is so placed that it can be used for hoisting. With the aid of block and tackle and a pair of steady horses the side of the tripod is raised from the ground to an upright position,—the third leg of the tripod is then raised and attached to the other two by ties and diagonals. The completed tripod is used to raise the two sides of the scaffold framed on the ground. After these sides are raised they are connected by ties and diagonals, thus completing the structure.

The plots of ground on which the towers are erected are leased at a nominal rental for a term of ten years. The thanks of all the Officials of the Survey are due to the various owners of lands found necessary for the work, and the uniform courtesy and desire to assist in every way possible have added materially to the comfort of the men engaged in the work of the Survey.

Stations on hill-tops where towers are constructed are marked by an underground mark consisting of a copper bolt set in concrete in a drain tile on end, below the frost line, and also by a surface mark of a similar nature placed twelve inches under the top of the ground. In addition to the marks underneath the tower, a reference monument of artificial stone is erected—usually in the nearest fence line. It is five feet high, twelve inches square at the surface of the ground and nine inches square at the upper end, and is set in a concrete base three feet square and of sufficient depth to be secure from the action of frost. This monument is connected with one of the primary lines of the Survey and will eventually have a copper plate on its base, on which will be marked its latitude and longitude. In the years to come—after the towers have been removed—these monuments will form the visible marks of the Survey. The underground marks will remain for the purpose of triangulation surveys in the future.

OBSERVING

The preparation of the stations for their occupation by the observing party is followed by the measurement of the angles by the surveyor in charge of that branch of the work.

The precision of geodetic surveys has always, to a large extent, been limited to the degree of perfection attained in the construction of theodolites. Geodesists in charge of the surveys conducted on various portions of the globe for more than a century have contributed their quota to the form of these instruments. Thus so many different ideas have been embodied in their design that it is questionable whether in their essentials the theodolites of to-day are any improvement upon those made by Ramsden in the eighteenth century. Unfortunately the desire for trivial conveniences which add to physical comfort has absorbed the attention of many observers, at the expense of more substantial improvements.

An instrument which is expected to be free from many of the imperfections of those now in use has been designed for the Canadian Survey, and its success is earnestly hoped for by other countries as well as Canada.

A geodetic theodolite consists essentially of two parts, a graduated horizontal circle and a telescope constructed to revolve on a centre common to both; there are also micrometer microscopes turning with the telescope in a plane parallel to that of the graduated circle. The circle can be moved around the common centre and clamped in any position leaving the telescope and its accompanying microscopes free to turn from point to point around the horizon. As each successive pointing on objects connected with the survey is made, the micrometer microscopes focussed on the graduated circle are read. The differ-

PLATE XXXV.

OBSERVING TOWER
CANADIAN GEODETIC SURVEY

Journal of the Royal Astronomical Society of Canada, 1912

ences between these readings is the measure of the angle in degrees, minutes and seconds -- between the points to which the telescope has been directed.

Of the various parts of a theodolite, the graduated circle is probably the most important. For modern geodetic work the diameter of the graduated portion is usually twelve inches, but circles thirty-six inches in diameter have been used. The circle is divided into four thousand three hundred and twenty parts, each covering five minutes of arc. The spaces are defined by fine marks on silver: excluding the widths of the marks each space covers less than one-hundredth of an inch. An error of one seventeen thousand of an inch in marking one of these lines would mean two seconds of arc or a horizontal displacement of six-tenths of an inch at a distance of one mile. The graduating marks are made by a sharp tool held nearly vertical, controlled automatically by a complicated engine made with the greatest precision. Provided all the frictional parts are free from appreciable dust particles, that all the sections of the engine the plate itself and the atmosphere in the room, are at the same temperature and remain so throughout the period of graduation, and that no controlling surface of the mechanical parts has become worn, the operator may expect success to crown his efforts. However, notwithstanding the supposed perfection of modern graduating engines, errors of from five to eleven seconds have been found in instruments in use in Canada.

All the parts of a theodolite should contract and expand uniformly during changes of temperature and yet the material used in construction must be hard enough to resist friction at many bearing surfaces. Various alloys have been utilized but unfortunately all alloys of metals are subject to molecular action which may distort, lengthen or contract the mass while aging is in progress.

In order that the fine marks on the circles of the theodolites may be accurately observed by the micrometer microscope referred to, their magnifying power must be high and the lenses of good quality. This results in sharp focussing, and the slightest change in focal distance causes the marks to disappear. The molecular changes referred to in the above paragraph, have distorted one of the circles now in use in Canada to such an extent that as the micrometers are revolved the graduations upon a certain section are appreciably out of focus. In the case of the circle referred to, the change appears to be a function of the temperature. In the Great Triangulation of India, the same difficulty has been encountered to a more serious extent than in Canada, perhaps on account of the higher temperatures experienced.

All branches of science depending upon mechanical measurements for their practical development encounter all manner of discouraging obstacles, the desire to attain a degree of refinement beyond a certain limit seems to challenge an array of trouble that is beyond conception. Geodetic surveys have always received especial attention of this nature. The instance of the graduated circle has been introduced as an example of what may be expected when one attempts to cross the boundary between ordinary and precise measurements.

An observing party, for observing horizontal angles, consists of a surveyor, a recorder, a cook and five or six light-keepers. The light-keepers are sent to the stations surrounding the one to be occupied. They show a light on the top of the tower from a point over the centre of the tripod which is also vertical to the station mark in the ground. In the daytime the light consists of a beam from the sun reflected along the line by means of mirrors; at night an acetylene gas lamp is used.

The surveyor measures the angles in succession around the horizon beginning at a station called initial. The telescope is directed to this station and after the micrometer microscopes are read the telescope is turned to the right until the next station is intersected. The microscopes are again read, and so on in succession until the initial station is again reached and read upon; the instrument is then reversed and another series of readings is made around the circle to the left. The two rounds of readings constitutes a determination of the angles, and sixteen determinations are made starting from as many different points on the graduated circle. The instrument is reversed between the rounds to correct certain defects in construction and adjustment; the direction of the round is changed to annul the effect of twisting of the tripod due to unequal heating and cooling of the timber of which it is constructed. The circle is moved in order that the readings may be spread over the graduations symmetrically, eliminating as nearly as possible the errors of spacing referred to in a previous paragraph. It may be said briefly that the whole system of measuring angles, or using instruments of precision for any purpose whatever, is designed to meet and, as far as possible, counteract the effects of their mechanical imperfections. After every known precaution is taken, there is always the knowledge that atmospheric conditions and changes must be encountered and these are so subtle and uncertain in their action that the work of an observer is no sinecure. The successful accomplishment of work of this nature within certain limits of precision which are fixed, is impossible to the careless and indifferent observer. From the time the first pointing is made until the night's work is finished the physical and mental strain is never relaxed. Each day and night brings its own atmospheric combinations; the various parts of the instrument are never at rest; at any moment something may occur which might destroy the accuracy of a night's work or, if not fatal, may introduce irregularities that harrow the nerves of the man at the eye-pieces. But in spite of this there are many compensations for an observer whose heart is in his work; he can derive a large measure of unalloyed pleasure from results that are entirely satisfactory. In addition to the measurement of horizontal angles angular distance from the zenith to all stations around the one occupied is also observed, in order that their relative elevations above sea-level may be computed. The datum of sea-level is obtained through connection with geodetic levels at points throughout the survey.

COMPUTING

The work in the field is followed by the office computations which begin at the primary base line and are carried through all the triangles to the next base, determining the lengths of all the sides, their astronomical azimuths — or courses — and the latitude and longitude of the angular points.

In connection with the work in the field the measure of accuracy is indicated by certain geometrical conditions which should be satisfied : *viz.*, the sum of all the angles measured around the horizon at a station, closing the circle, should be three hundred and sixty degrees, and the sum of the three angles of each triangle should be one hundred and eighty degrees plus the spherical excess.

The triangles of a Geodetic Survey are so large that the spherical form of the earth must be taken into consideration. The angles at the three angles of the triangles, are the angles of inclination of planes which intersect near the centre of the earth and are, therefore, in excess of three right angles. The amount of this excess in a given latitude is proportional to the areas of the triangles. This very casual statement of the theory of spherical triangles is sufficient for the purpose of this paper ; it explains the means at the disposal of the surveyor in the field for checking the work as it proceeds.

On account of the imperfection of theodolites, and many other adverse conditions met with in measuring the angles, the results do not satisfy the geometrical requirements ; the sums of the angles measured around the horizon are not equal to three hundred and sixty degrees, and the sums of the three angles of the triangles are not equal to two right angles plus the spherical excess. With reference to the latter requirement, the Geodetic Survey of Canada has adopted the standard of one second of arc as the average summation error allowable. With regard to the error of closure of the circle, the instructions issued to observers of horizontal angles do not allow any latitude beyond the probable error of the determination of the angles.

The principal work of the computing staff consists of the adjustment of the triangles, which are combined, forming figures which are most convenient for the determination of the small errors of closure.

All precise work having for its object the measurement of small magnitudes is subject to error, even if mechanical adjuncts were perfect and there were no adverse conditions of atmosphere or temperature, personal error would have to be reckoned with. After every known precaution has been used, the writer is of the op ion that in astronomical and geodetic work, error due to uncompensated personal equation still exists. As a simple illustration of this statement the observations on a signal light may be u-ed.

The days when observations are possible are not of frequent occurrence. An observer commences work at three o'clock in the afternoon. His observations are made by adjusting his telescope so that the spider lines intersect an image consisting of rays of light which come from a mirror, perhaps, forty or fifty miles distant. Owing to intervening physical conditions the atmosphere is boiling, and the rays of light are, in addition to uncertain flashing, gyrating over a large portio.: of the field of view of the telescope. For the purpose of this class of work two vertical spider lines are used; the observer watches the movements of the signal light, at the same time adjusting the telescope until the flashings are apparently covering equal areas outside of the vertical lines. The next signal to which the telescope is directed is probably thirty miles from the first and only twenty from the observer. In the meantime clouds may have drifted across a portion of the second line and the signal light looks like a first magnitude star; and so on around the circle, no two images alike. At night an entirely different image is seen, that of an acetylene lamp observed in a telescope illuminated artificially. As the day and night progresses the physical and nervous strain becomes evident — some of the pointings are made with less care, or even with equal care but impaired judgment, and the work between three and four o'clock in the afternoon and between one and two o'clock in the morning may be expected to be appreciably different.

It is assumed that all observations are in error and that if a triangle closes without any indicated error, the apparent perfection of the work is due to accidental compensation. The adjustment of the triangles and their figure combinations consists of a distribution of the errors of closure which is accomplished by means of the method of least squares; in other words the corrections applied to the angles of a figure are such that the sum of their squares is a minimum.

The figure adjustment is followed by the computations of the lengths of the sides; and of the differences of latitude, longitude and azimuth, from station to station throughout.

ASTRONOMICAL OBSERVATIONS

The accuracy of all astronomical observations is to a large extent dependent upon spirit levels, which are supposed to indicate the direction of a horizontal plane. Unfortunately they are influenced by the unequal distribution of gravity and the uncertainty of the results of astronomical observations referred to in a previous paragraph is due to this influence. The variation of gravity is caused by the unequal density of the earth's crust and by inequalities on its surface. If the uncertain results were in proportion to the visible mass, the computation with the contour of the surface as data would be comparatively simple, but the actual variations of instrumental results are at some places on the surface of the earth in opposition to that theory (See *Philosophical Transactions*, 1855–59). In the vicinity of Moscow on a comparatively level plain, the variation amount to sixteen seconds of arc in sixteen miles: that is to say, astronomical observations for latitude on the same meridian at two points sixteen miles apart would indicate that the points were sixteen miles and sixteen hundred and seven feet apart, an error of nearly one-third of a mile. A geodetic survey enables astronomers to make their computation with reference to the relative latitude and longitude of the stations of the survey with certainty; and astronomical observations at a number of stations throughout the survey will furnish a mean astronomical datum which will be sufficiently near the truth to satisfy the scientific requirements of the survey. This branch of the work is of absorbing interest. It deals with a subject that would furnish most interesting material for discussion but the time at our disposal does not admit of more than passing notice.

GENERAL REMARKS

Owing to the delay in starting a Geodetic Survey in Canada, the demand for its existence has arisen in isolated provinces causing a distribution of the work to meet as nearly as possible the requirements of the country. Geological Surveys in the Maritime Provinces; International Boundary Surveys west of Lake Superior and the rapid development of British Columbia; have demanded immediate attention. The more thickly populated Provinces of Ontario and Quebec are now being mapped topographically, requiring the angular points of the Geodetic Survey for the purpose of the projection of the maps.

The triangulation has been completed over the following areas: the Provinces of Nova Scotia and New Brunswick, three thousand eight hundred and forty square miles; Quebec and Ontario, thirty-four thousand three hundred and thirty and in British Columbia, one thousand four hundred and thirty square miles. Observing stations have been prepared for the further extension of the survey over two thousand two hundred and fifty square miles in Nova Scotia and New Brunswick, fifteen thousand and ninety square miles in Ontario and one thousand four hundred and thirty square miles in British Columbia.

Reconnaissance surveys have been extended over an area of twenty-seven thousand five hundred square miles in the Provinces of Nova Scotia, New Brunswick, Ontario and British Columbia.

In addition to primary triangulation for the purpose of the Geodetic Survey, spirit levelling of the highest order of precision has been in progress since nineteen hundred and seven; two thousand six hundred and twenty-seven miles have been completed in the Provinces of Nova Scotia, New Brunswick, Quebec and Ontario. The limit of error allowed is 0′·017 M; "M" being the distance in miles. The only circuit closed is four hundred and twenty-one miles long; the indicated error is 0′·16; less than one half the error allowable.

DOMINION OBSERVATORY,
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