"Report of Progress," 1882-83-84. Montreal, 1885. "Maps o accompany Report of Progress, 1882-83-84"; and "Catalogue of Canadian Plants, Part II, Gamopetalæ," by John Macoun, M.A., F.L.S. Montreal, 1884. From the Director, Geological and Natural History Survey of Canada.

"The Australian Irrigationist," No 13. Melbourne, 1885. From the Editor.

The following papers were read:—

"THE PAPUANS—COMPARATIVE NOTES ON VARIOUS AUTHORITIES WITH ORIGINAL OBSERVATIONS," by William E. Armit, F.L.S., F.R.G.S., Pages 95-116.

A SHORT ACCOUNT OF THE MEASUREMENT OF THE BASE LINE IN CONNECTION WITH THE TRIGONOMETRICAL SURVEY OF QUEENSLAND.

BY

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(PLATE V.)

I propose giving a short account of the measurement of the base-line in connection with the Trigonometrical Survey of the Colony, which was completed last year.

A base-line is the foundation of a trigonometrical survey. On the accuracy of its measurement depends the correctness of the net-work of triangles, which are established by angular measurements, commencing from the terminal points of the base. The exact measurement of a line on the earth's surface is one of the most difficult operations that can be undertaken. Even with the greatest care and the most approved appliances only a close approximation to absolute accuracy can be relied on. Experience proves that no two measurements of the same line exactly agree; there is always a small difference, and though such difference may be inconsiderable, and even unappreciable, what is styled "mathematical accuracy" cannot be attained. The earlier measurements in such surveys were conducted under circumstances less favourable to accuracy than those obtaining at the present day. We have now the experience gained by each successive survey, the history of which has been carefully recorded. It would take too long to give particulars of the several bases that have been measured successfully, although much interesting matter would be found in their recital.

The chief difficulty is obtaining a *unit* of *length*, by means of which the measurement is made. Almost all substances, metallic or otherwise, expand and contract with heat and cold: so that it will be understood in determining the length of any line when measured by means of a rod, or chain, made of a material liable to fluctuation, it is necessary to know what its absolute length is at some known temperature. This temperature is usually fixed at about 62° Fahrenheit. The standard of the Ordnance Survey in Great Britain is ten feet in length, and one of the same length was used in this Colony. This length is nominal, and is only correct when the temperature is 64°2. The details of the methods used for determining the length of a standard would provide material for a separate paper, and I shall only refer to the subject by mentioning that the comparisons of standards often occupy months, and the greatest care is taken that the thermometers and micrometers used are of the best workmanship. At the Ordnance Survey Office, Southampton, is a building specially constructed for the purpose. The inner room, where the comparisons are made, measures twenty feet by eleven, with thick double walls, and is sunk below the level of the ground, and roofed with nine inches of concrete. An outer building entirely encloses and protects the room from external changes of temperature. This will give an idea of the accuracy aimed at in these comparisons. Each division of the micrometer microscopes used is about one-millionth of a yard.

The determination of the temperature is of the utmost importance. The thermometers used require to be accurately graduated, and their index errors ascertained by careful comparisons with a standard thermometer. The co-efficient for expansion is the same as that used for steel bars, and amounts to ·007632 inches in one hundred feet for one degree of temperature. This co-efficient is the one invariably adopted, and has been tested many times by the most careful experiments. The standard of our Queensland Survey is a bar of steel, floating in mercury, the length of which was determined by careful comparisons with the standard bars in the Sydney Observatory, which have been supplied by the Board of Trade in London. This bar has a length of 9·9998581 feet, at a temperature of 62° Fahrenheit; so that, applying the above co-efficient for expansion of steel, its length at any other temperature can be determined.

Having been provided with a standard, it was necessary to decide how the base should be measured. Having given the subject careful consideration, I determined to use a steel tape of one hundred feet in length, with such appliances as would ensure a high degree of accuracy. The experience subsequently gained in the measurement proves that I was right, as it is now clearly established that, with proper care, a base-line can be measured with equal accuracy with a one hundred-foot tape as with bars of shorter length. The next step was how to ascertain the length of the tape with reference to the bar. The necessity for doing this had not arisen before, as most of the base-lines had been measured with wooden or steel rods ten feet in length. I was fortunate enough in having Mr. Adams, the Surveyor-General of New South Wales, and Mr. Russell, the Government Astronomer of that Colony to assist me, and between them they devised an apparatus, by means of which a tape of one hundred or sixty-six feet can be compared with the standard bar, and its length accurately determined. The result of the several comparisons, and the temperatures at which they are taken are given in the Appendix A. It will be seen that two tapes (A and B) were used in the measurement of the base, and the length adopted for each tape was the mean of twelve comparisons taken at different times. The apparatus referred to is similar to those used for comparing bars of assumed equal lengths. It has micrometer microscopes attached by which the smallest differences between the bar and each tenth part of the tape, with which the comparison is made, can be determined. The temperature is observed by means of the best thermometers, the index errors of which are known.

The base line is situated on the open plain known as the prairie plain, between Mount Irving and Mount Maria, the summits of which are the terminal points. The former mount is about 215·8 feet, and the latter 162·5 feet above the level of the plain. The principal reason for selecting Mounts Irving and Maria, as terminal points of the base, were that observations could be made more accurately from their summits than from the terminals on the plain, where the atmospheric conditions were less favourable for the use of telescopes of high magnifying power. At first it was decided that the base should be confined to the plain, on the line extending from one summit to the other—the length of the sections at each end of the base being computed by triangulation. When the measurement commenced it was proved to my satisfaction that the terminal sections could be measured without risk of error. The ascent to the summit of Mount Maria is a gradual slope, so that no difficulty was experienced there. Mount Irving is rocky and more abrupt, necessitating a track being cleared and levelled In the case of the latter section the measurement was carried out three times—two of them in opposite directions. The length was also computed by means of triangulation, as a check upon the work. The plain was, moreover, very suitable for the operation in so much that it was surrounded by hills, which permitted of stations being readily obtained for extending the triangulation.

All the preparations having been made, and the plant brought to the ground, the measurement was commenced on August 24th, 1883, under the superintendence of Mr. District Surveyor McDowall, assisted by Mr. R. Hoggan. The base was divided into ten sections: the six central ones averaging nearly a mile, and the two others at each end being nearly half-a-mile long. The terminal points of these sections were marked by stones sunk into the ground and set in concrete. Each stone had a metal plug, upon which a small mark was made denoting the terminal point of the section. The tapes used on the survey were about half-an-inch wide, and little more than a hundredth of an inch thick. The one hundred feet lengths are denoted by minute dots, or spots, on silver discs, which were inserted in the tapes, about six inches from each extremity. The method adopted was as follows:—the tapes A and B were laid side by side in the troughs. These troughs were made of Kauri Pine (Dammara robusta), one inch thick, which being a light wood and a good non-conductor of heat was found well-suited for the purpose. Each trough was about fifteen feet in length, so that they could be easily carried; and whilst the measurement was being carried on with one hundred feet, the troughing for the next one hundred feet was being placed in position. There was some difficulty at the outset in devising suitable covers for the troughing—so as to shade the tapes from the direct rays of the sun. A strip of blanket was used at first, but was not found to answer. After some trials, a board, sufficiently wide to shade the bottom of the trough, whilst allowing for ventilation, was used, with the best results. Our subsequent experience proved the boards to be reliable in every way. The troughs were supported upon pegs set on an even grade by means of a levelling instrument. Each sub-division of one hundred feet was marked by a piece of sawn hardwood, 4 x 4 inches, and three feet long, strongly driven into the ground. On the top of the peg a small copper stud, with a flat disc (a copper rivet was used for the purpose) was inserted to receive the mark at the end of each hundred feet. Three measurements were made with each tape, each one distinct and independent, so that every section has been measured six times. A tension of 20 lbs., by means of a spring balance, was applied to each tape. The following extract from the instructions issued for the guidance of the surveyors employed in the measurement will supply the particulars in regard to the microscopes used. I have brought down similar ones for the inspection of members:—

"Two microscopes are to be used—one at each end of the tape. The 'following' one is for the purpose of keeping the end of the tape and the mark previously made on the copper stud co-incident, whilst, by means of the 'leading' microscope, a mark is made on the copper stud, as nearly as possible agreeing with the terminal point of the steel tape. The 'following' microscope being set to zero, the 'leading' one is used for the purpose of comparing the mark made on the copper stud with the terminal point of the tape in each measurement, and registering the micrometer value of the interval—if any—between them. The micrometer microscopes used have a value represented by two revolutions of the screw to one hundredth of an inch; and with the view of lessening the risk of error by recording *plus* and *minus* readings in the field book, the reading of the 'leading' micrometer is assumed to be twenty revolutions at zero; so that all readings above twenty are *plus*, and all below *minus*. It will be observed that the reading is from the point marked on the stud to the terminal point on the tape—the measurement from a fixed point to one liable to fluctuation by temperature, being more reliable than were the measurement taken in the reverse way."

Immediately after each measurement was made and recorded, readings were taken from five standard thermometers which were placed alongside of the tapes at equal distances, fifteen readings were therefore taken during the three measurements of each tape. The mean of these readings must approximate very closely to the true temperature. The thermometers used were very carefully compared with a standard which was procured from the observatory in Sydney, and the index errors determined. It is not probable that the temperature adopted is more than one-fifth of a degree Fahrenheit in error, but even were it in error half a degree it would not affect the length of the base by more than 1·3 inches.*

The principal advantage of the system adopted, apart from the greater speed with which the measurement could be carried out, was the means it provided for checking the work as it proceeded. In consequence of the length of the tape its fluctuations as the temperature altered were quite appreciable. I recollect when working at one of the microscopes seeing the tape visibly contract as a cold blast of air entered the troughs. It was often observed that the tape was more sensitive than the thermometers, and we often had to wait until the latter had settled down to the temperature of the tape. The co-efficient for ex-

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*After the base line had been measured six thermometers were supplied from the Royal Observatory, Kew, England, in response to the following special application made to G. M. Whipple, Esq., Superintendent:—

"QUEENSLAND.
"SURVEYOR-GENERAL'S OFFICE,
"BRISBANE, *22nd Jan.*, 1884.

"SIR,—I trust I am not trespassing on your kindness in asking you to assist me in procuring a set of thermometers for the use of this department, in connection with the measurement of base lines in the field.

"I am anxious to have 12 thermometers sent to me of a class suitable for recording the temperature in such measurements where great accuracy is required. It is found, by experience, in sudden changes of temperature, that the steel tapes are more sensitive than ordinary standard glass thermometers; and it is possible that some modification pansion was as before stated ·007632 inches for each degree of the thermometer, so that it was easy to determine whether any excess or deficiency in the length of the tape agreed with the micrometer. The corrections from one to six degrees are as follow:—

1°	·00763 inches.	4°	·03052 inches.
2°	·01526 „	5°	·03815 „
3°	·02289 „	6°	·04578 „

One to eight revolutions of the micrometer represent the following fractional parts of an inch, viz.:—

1 revolution.	·005 inches.	5 revolutions.	·025 inches.
2 „	·010 „	6 „	·030 „
3 „	·015 „	7 „	·035 „
4 „	·020 „	8 „	·040 „

It will be seen by a comparison of these values that three revolutions of the micrometer nearly equal the correction for two degrees of temperature, whilst the expansion or contraction for five degrees of temperature nearly equals eight revolutions of the micrometer. The relative values of the micrometer

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of the clinical thermometer might be devised to answer the purpose. What is required is sensitiveness, combined with stability of construction. It will be understood that very delicate glass thermometers are so liable to break that they are practically worthless in field use.

"The thermometers should be graduated to 0·2 of a degree, and should range from 32 to 125 degrees. I enclose a letter from Mr. Cassella, who appears to have given the subject some consideration. You might, at your convenience, arrange to see him and ascertain whether he has anything to suit my wants. Any expense will be met as soon as you advise me.

"You will excuse my troubling you in this matter. I wish to have the most suitable class of instruments that can be procured, and I believe you can assist me better than anyone else.

"I have the honor to be, Sir,
"Your obedient servant,
"(Signed) W. ALCOCK TULLY,
"Surveyor-General.

"G. M. Whipple, Esq.,
"Superintendent Royal Observatory,
"Kew, England."

measurements and the corrections for temperature were readily borne in mind, and, whilst the measurement was being carried out afforded a most efficient check, any divergence being at once noticed, and as it indicated that the thermic conditions of the tape and the thermometers did not agree, one or more additional measurements were taken until the opposing differences were reconciled. Whilst the temperature was steady the micrometers and thermometers worked together most harmoniously—rapid fluctuations on the contrary produced conflicting readings. The advantage of having such a check cannot be over-rated. It gave an additional value to the work. The confidence which it engendered reacted on the observers and enabled them to give a more undivided attention to the details than was possible under other circumstances.

I give in appendix B the computed lengths of each separate measurement and the difference between the mean of each section. The difference between the mean of the three measurements of each tape was ·1845144 inches, which is not quite $\frac{2}{10}$ of an inch. The adopted lengths of the tapes were as follow:—

Tape A	- - -	99·9980561 feet
Tape B	- - -	99·9976211 „
Difference	- -	·0004350 „

This fractional part of a foot is nearly equivalent to $\frac{1}{200}$ of an inch. This difference in length between the two tapes, were it constant throughout the entire distance from end to end of the base, would have amounted to 1·8 inches; but as the actual difference between the measurement by each tape was not quite $\frac{2}{10}$ of an inch, it proves that about an inch and a half of the theoretic difference was absorbed by errors of observation or other counterbalancing cause. The measurement by each tape has equal weight, and the mean of the two is only affected by the above absorption to the extent of ·7 of an inch. The above values in dealing with a base exceeding seven miles in length are so small that it is scarcely necessary to take account of them, and I only refer to them in this paper to show how the difference in the computed lengths of the tapes was disposed of. In order further to test the accuracy of the measurement of the whole line, a system of triangles was established by which the length of half the line was computed and compared with the measured length of the same portion. The differences between the computed and measured length of the half was found to be only ·936 of an inch, which is a most satisfactory proof of the care exercised in the measurement as well as of the system adopted in carrying it out.

The line was measured, as before stated, in grades from peg to peg in 100 feet lengths. These lengths represented the hypothenuse of a right-angled triangle of which the side next in length represented the actual horizontal length between the pegs. A reduction of the measured length to the horizontal had to be made and computed for each subdivision. The correction, unless for the two terminal sections, was very small. The measured length being the hypothenuse, and the rise or fall between the pegs, as the case may be, being the smallest side of the triangle, it was easy to find the third side. For convenience of calculation the difference of the squares of these two sides was found by the well-known formula of multiplying the sum and difference of the sides, and then extracting the square root of the product. This gave the horizontal length. The total correction for reduction to the horizontal was 31·123 feet, of which 19·732 feet was for the Mt. Irving section, and 11·225 feet for that of the Mt. Maria end.

The base was computed by logarithms, so that each stage of the process, from the entry in the field notes to the final determinations, could be traced step by step. It was a more laborious process than the ordinary arithmetical way, but it has the advantage of showing every detail of the calculation, and has necessarily greater weight than if the base were calculated in the other way.

[At this stage the author exhibited, for the information of members, a book in which the results of the computations had been entered, and also some other papers relating to the subject.]

The base line being measured on a plain with an average height of 1298 feet above the sea level had to be reduced to that level. This reduction was effected by the formula:— "Multiply together the base and height, and divide the product by the radius of the earth, and the quotient will be the correction to be deducted from the base." This correction amounted to 2·2520 feet which had to be subtracted from the measured length.

The probable sources of error were also investigated. None of them were likely to affect the accuracy of the work, and as they would not act in the same direction, the result would be according to the law of compensation that one would tend to counteract the others.

The whole work depends on the correctness of value given to the standard bar used on the survey. It will be understood that a very small error in the length of the bar will more than overbalance all other errors that can arise.

The several sources of error are as follow :—

1. Error in determining correct temperature.

2. The co-efficient used for expansion not being applicable to the steel of which the tapes were composed.

3. The liability of the tapes being out of line. It may be mentioned that a declination of one inch out of the line in three places throughout the whole base will give a possible error of ·64 inches. A declination of one inch from the straight line in the middle of each tape would produce an error of 0·05 inches in the whole base.

4. Frictional error by affecting the tension.

5. Errors in micrometers. This would necessarily be very small, if any, as the micrometers are only responsible for the measurement of 1·018 inches of the whole base.

The extreme error possible under any of the above—Nos. 1 and 2—would not exceed an inch, and in the others it would amount to a very small fraction. Having given the question careful consideration it was determined not to make any allowance for these small errors.

I have endeavoured to give a general idea of the details of the measurement, avoiding as far as possible technicalities which would only be understood by the profession. As a rule the general public take little interest in the execution of these surveys. They may acknowledge them to be necessary, but do not care to know the processes by which they are carried out. I am glad of the opportunity the Royal Society has afforded me of placing the results of the measurement on record, and trust I have succeeded in interesting the members whilst dealing with a somewhat dry subject:—

APPENDIX A.

Determination of the Length of Tapes A and B used in Measurement of Base Line.

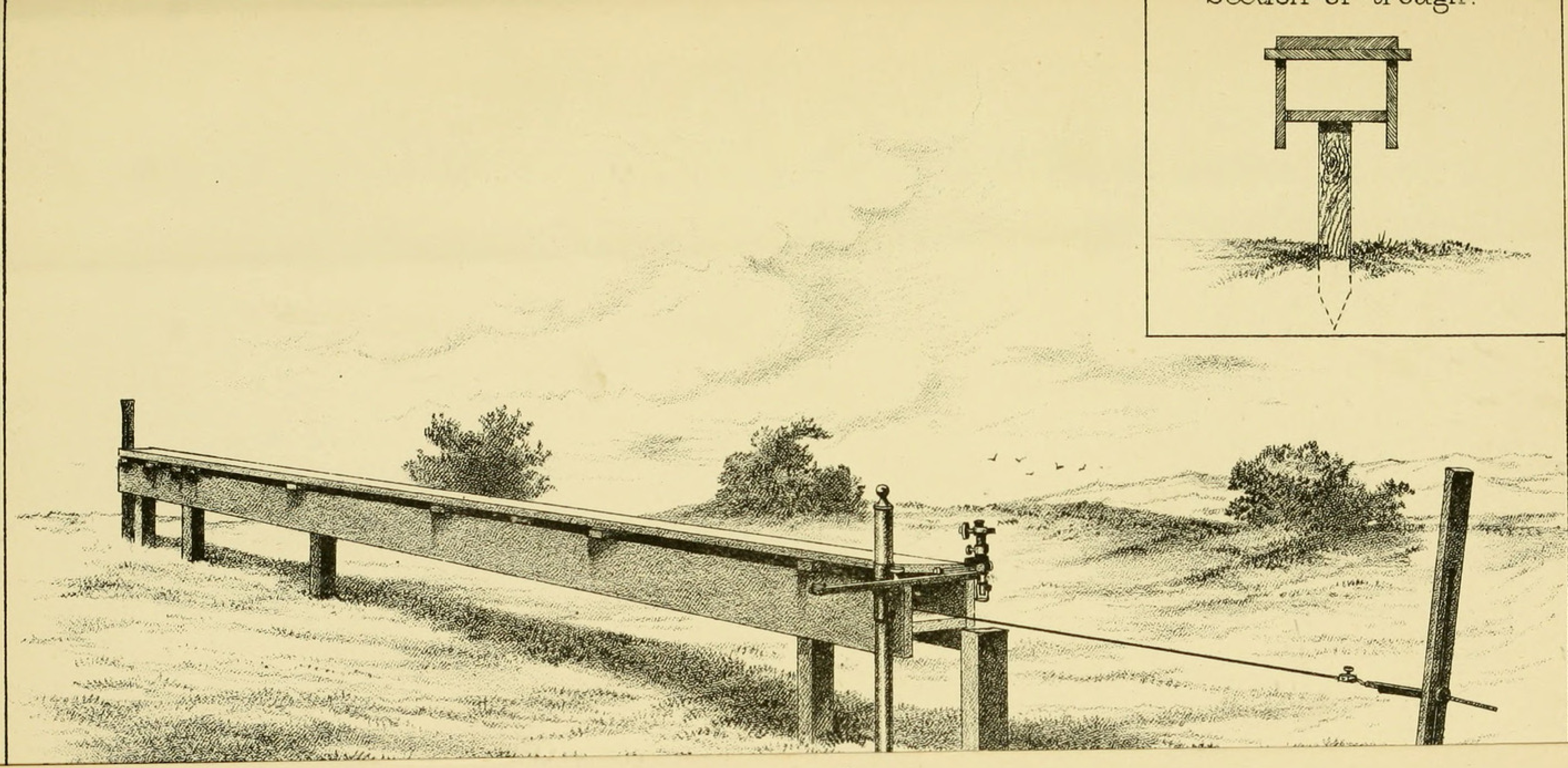
100ft. Approx.—Tape A.			100ft. Approx.—Tape B.			Tension, 20 lbs.
Date of Measurement.	Temperature.	Length at 62deg. Faht.	Date of Measurement.	Temperature.	Length at 62deg. Faht.	
1883.		FEET.	1883.		FEET.	
Sep. 14	66·5	99·9977453	Sep. 14	67·9	99·9969864	
„ 15	66·0	99·9978127	„ 15	66·5	99·9970344	
Nov. 7	72·5	99·9983970	Nov. 8	72·0	99·9977527	
„ 7	73·0	99·9980835	„ 8	73·5	99·9974246	
„ 7	73·5	99·9980573	„ 8	73·5	99·9975248	
1884.			1884.			
May 16	61·0	99·9975325	May 16	63·0	99·9976441	
„ 17	61·0	99·9975197	„ 17	62·5	99·9978327	
Aug. 8	64·0	99·9982328	Aug. 7	64·0	99·9973815	
„ 8	64·5	99·9985049	„ 7	65·0	99·9980631	
„ 9	63·5	99·9986753	„ 9	64·5	99·9985667	
Nov. 1	72·0	99·9968217	Nov. 1	74·0	99·9976355	
„ 3	72·0	99·9964533				
Adopted mean -		99·9980561	Adopted mean -		99.9976211	

APPENDIX B.

Measurement of Entire Length of Base Line (from Summit of Mt. Irving to Summit of Mt. Maria).—Tabular Results in Feet.

		Deg.	A1.	A2.	A3.	Mean A.	Difference of Means.	Mean B.	B1.	B2.	B3.
1884.	Mt.										
Sep.-Oct. ...	Irving.	70	2546·4099339	2546·4160688	2546·4153823	2546·4137949	0·0039618	2546·4098331	2546·4103215	2546·4096699	2546·4095079
Sep.	1	73	2499·9667170	2499·9666739	2499·9672573	2499·9668827	0·0088902	2499·9757729	2499·9759511	2499·9768418	2499·9745260
1883.											
Aug. 31-Sep. 7	2	71	4700·1733328	4700·1717090	4700·1725780	4700·1725399	0·0014832	4700·1740231	4700·1774686	4700·1721419	4700·1724595
Sep. 9-Sep. 25	3	78	4000·3494483	4000·3464889	4000·3468172	4000·3475850	0·0043652	4000·3519502	4000·3523487	4000·3506108	4000·3528908
Sep. 25-Oct. 2	4	75	5000·2951300	5000·2961735	5000·2939590	5000·2950878	0·0015760	5000·2935118	5000·2956193	5000.2925837	5000·2923332
Oct. 2-Oct. 6	5	74	4500·2447470	4500·2432462	4500·2420932	4500·2433621	0·0167685	4500·2265936	4500·2277747	4500·2267747	4500·2252314
Oct. 8-Oct. 11	6	76	4500·3290552	4500·3325728	4500·3318397	4500·3311559	0·0030507	4500·3281052	4500·3275099	4500·3288525	4500·3279529
Oct. 12-Oct. 19	7	79	5000·4716607	5000·4725609	5000·4745378	5000·4729201	0·0036514	5000·4692687	5000·4685280	5000·4709806	5000·4682975
Oct. 19-Oct. 22	8	84	2000·0939146	2000·0957883	2000·0963933	2000·0953638	0·0001460	2000·0952178	2000·0951609	2000·0949132	2000·0955782
Oct. 22-Oct. 24	9	89	2281·4195725	2281·4209571	2281·4229186	2281·4211496	0·0046472	2281·4257968	2281·4256613	2281·4260411	2281·4256882
			37029·7535120	37029·7622394	37029·7637764	37029·7598418	0·0097686	37029·7500732	37029·7563440	37029·7494102	37029·7444566

Mean - - 37029·7549575.


Section of trough.