GENERAL REPORT

ON THE OPERATIONS OF

The Great Trigonometrical Survey of India,

DURING

1876-77.

PREPARED FOR SUBMISSION TO THE GOVERNMENT OF INDIA,

BY

COLONEL J. T. WALKER, C.B., R.E., F.R.S., &c.,
SUPERINTENDENT OF THE SURVEY.

CALCUTTA:
OFFICE OF THE SUPERINTENDENT OF GOVERNMENT PRINTING.
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THE several operations of the present year, taken in the order in which they are described in this Report, are as follow :—

			Page of Report.	Page of Appendix.
No.	I.—*Trigonometrical.*	The Madras Coast Series ...	3	3—a
,,	II.—*Trigonometrical.*	The Secondary Triangulations in the Assam Valley ...	4	9—a
,,	III.—*Trigonometrical.*	The Secondary Triangulations in Burmah	5	12—a
,,	IV.—*Trigonometrical.*	The Eastern Frontier Series, Moulmein	6	14—a
,,	V.—*Trigonometrical.*	The Eastern Sind Series, Meridian 70°	7	16—a
,,	VI.—*Topographical.*	The Survey of Kattywar ...	7	17—a
,,	VII.—*Topographical.*	The Survey of Guzerat ...	8	21—a
,,	VIII.—*Topographical.*	The Survey of Kumaon and Garhwál	10	29—a
,,	IX.—*Spirit Levelling.*	Operations in Guzerat ...	11	34—a
,,	X.—*Tidal Investigations.*	Analysis of observations at tidal stations in the Gulf of Cutch and at Tuticorin ...	12	...
,,	XI.—*Tidal Investigations.*	Programme of Future Operations... ...	17	...
,,	XII.—*Geodetic.*	Electro-telegraphic determinations of Difference of Longitude ...	18	35—a
,,	XIII.—*Geographical.*	Explorations on Northern Trans-Indus Frontier	21	...
,,	XIV.—*Head Quarters Offices.*	Computing; Printing; Drawing; Photozincographic; Correspondence; and Stores ...	23	56—a

(2.) The operations carried on during the year under review have produced the following out-turn of work. *Principal Triangulation :* 67 triangles have been measured, fixing 53 new stations and covering an area of 5,019 square miles, in three series or chains, which, if united, would extend over a direct distance of 269 miles; astronomical azimuths of verification have been measured at two of the principal stations. *Secondary Triangulation :* an area of 5,400 square miles has been closely covered with points for the topographical survey ; an area of 3,100 has been operated in *pari passu* with the principal triangulation ; and in an area of about 23,600 square miles, lying mostly in portions of the Himalayas which are inaccessible to Europeans, a number of points have been fixed which will be valuable for geographical rectifications. *Topography :* areas of 959 and 640 square miles have been completed, on the respective scales of half an inch and one inch to the mile, in the British portions of the higher Himalayas ; and an area of 3,704 square miles has been completed, on the two-inch scale, in portions of the Bombay Presidency, in the course of which 2,717 linear miles of boundary and check lines were surveyed. *Geodetic Operation :* the amplitudes of three arcs of parallel, between trigonometrical stations in Southern India, were determined by the electro-telegraphic method; and the differences of longitude between Bombay, Aden, and Suez have also been determined in the same manner. *Geographical Explorations :* much valuable work has been done on the unsurveyed portion of the River Indus, and in and around the Kohistan which contains the sources of the Swat and the Panjkora rivers.

(3.) The principal triangulation has been executed in the usual manner with the great theodolites—instruments whose azimuthal circles have diameters of either 36 or 24 inches. The average theoretical probable error of the angles, as deduced from the evidence of the several measures of each angle,—and the average geometrical error of the triangles—the amount by which the sum of the three angles of each triangle exceeds or is in defect of 360° + the spherical excess—are shown in the margin, for each of the three series in which principal triangulation was carried on during the present year.

Series described in Section	Probable errors of observed Angles.		Geometrical errors of Triangles.	
	Number.	Magnitude.	Number.	Magnitude.
I ..	51	±0″·17	18	0″·81
IV ...	31	·42	17	·46
V ...	96	·14	32	·36
Averages ...	..	0″·20	...	0″·51

(4.) The administration of the department during the year devolved first on Major H. R. Thuillier, R.E., from the 4th April to 31st October 1876, and afterwards on J. B. N. Hennessey, Esq., M.A., F.R.S., &c., from the latter date until the 13th January 1877, during my absence in Europe on furlough. The report for last year was drawn up by Mr. Hennessey.

(5.) I now proceed, as usual, to report on, and give an abstract of, the several operations. Further details will be found in the extracts from the Narrative Reports of the Executive Officers, which are given in the Appendix.

No. I.—TRIGONOMETRICAL.

THE MADRAS COAST SERIES.

PERSONNEL.

Captain T. T. Carter, R.E., Deputy Superintendent, 3rd Grade.
Mr. G. Belcham, Surveyor, 4th Grade.
„ C. D. Potter, Assistant Surveyor, 1st Grade.
„ A. H. Bryson, „ „ 3rd „

(6.) The charge of the Madras Party was taken over by Captain Carter, R.E., on his return from furlough on 20th November 1876, from Captain Campbell, R.E., who had held it as a temporary measure during the recess, on Major (now Lieutenant-Colonel) Branfill's departure to Europe in May.

(7.) Captain Carter lost no time in making his preparations for taking the field, and he reached the scene of his operations by 1st December. During the preceding season, nearly all the stations had been chosen and built for two hexagons in advance of the final triangulation. Captain Carter's first care was to complete these stations, choosing definitely those which remained doubtful, clearing the rays where necessary, and building the pillars and scaffoldings for the instrument and signallers. He then took up the final triangulation, and during the season completed these two hexagons, and a third which his assistants had selected and prepared in the meantime. The season's work also included the selection and building of stations, and the clearance of rays for another hexagon in advance of those finally observed; and one astronomical determination of azimuth.

(8.) The country is very unfavourable for triangulation, being flat, with innumerable groves of valuable trees. The villages are numerous, and each covers a great quantity of ground; locomotion, moreover, is by no means easy, owing to the want of roads. The famine, which was raging in Southern India during the season, made the question of supplies a difficulty; prices being excessively high, and the inhabitants sometimes unwilling to provide food at any price offered. During the beginning of the season, a water famine also seemed imminent, and there was a good deal of cholera in the district. Considering that the country was new to him and the difficulty he met with, the out-turn of work is very creditable to Captain Carter, who was, as he reports, well seconded by his assistants.

(9.) To obviate the necessity of heavy expenditure in building towers at the stations, Lieutenant-Colonel Branfill had introduced in the previous season a system of raising the signals on lofty scaffoldings, and the theodolite on a high tripod-stand of wood. This system was followed by Captain Carter, the signal being generally raised 45 feet, and on one occasion as high as 60 feet, from the ground, while the theodolite was generally raised about 24 feet. The system requires extra care on the part of the signallers in plumbing their signals over the station-marks, but it has been found to work well; and it certainly effects a considerable saving of expense, for it enables the triangulation to be carried on without the construction of substantial masonry pillars raised to a height of 20 to 30 feet above the general level of the plains, as is otherwise necessary. The advantages from an economical point of view have, however, been allowed rather more weight than is altogether desirable. The principal stations have been raised to a height of only one or two feet above the ground-level, which is scarcely sufficient to enable them to be readily identified many years hence, when the present generation has passed away, as it is desirable that they should be. Instruction have therefore been issued to Lieutenant-Colonel Branfill to raise all stations situated on level ground to a height of not less than 10 feet, and then to erect the tripod for the theodolite, or the scaffolding for the signals, on them. Thus the requisite command of view will be secured by temporary arrangements without undue sacrifice of prominence and permanence in the structure of the stations.

(10.) The nature of the country precluded the possibility of executing much secondary triangulation, but whatever was practicable was accomplished. Captain Carter endeavoured to find all the stations of the old triangulation by

Colonel Lambton, which he knew to be in his neighbourhood, with a view to their incorporation in his own triangulation; but in only one case was he successful. This points to the importance of carefully marking the principal stations of this Survey at the outset; it is now evident that this was not sufficiently attended to originally.

(11.) Lieutenant-Colonel Branfill returned from furlough, and relieved Captain Carter of the charge of the party, on the 1st June 1877. The reductions of the observations, and the construction of the preliminary chart, have been completed under his supervision. He has also prepared a list of the commonplace names met with in the districts operated in, with their traditional root-meanings and local applications, which is very interesting; it will be found at page 5—a of the Appendix.

No. II.—TRIGONOMETRICAL.

THE SECONDARY TRIANGULATION IN THE ASSAM VALLEY.

PERSONNEL.

Lieutenant H. J. Harman, R.E., Officiating Assistant Superintendent, 2nd Grade.
Mr. O'Sullivan, Surveyor, 4th Grade.
" J. F. McCarthy, Assistant Surveyor, 4th Grade.

(12.) These operations have been carried on by Lieutenant Harman, R.E., with his customary energy, and, on the whole, with good results, notwithstanding the many difficulties met with.

(13.) It was mentioned in the general report for 1875-76 that two hill-peaks affording desirable sites for survey stations were unfortunately in the Abar territory, and that the permission of the Abar chiefs to visit them had been sought in vain. During the past season arrangements were sanctioned by the Government to permit of Lieutenant Harman's visiting these peaks with an escort of 100 men of the 44th S. L. I. This measure was carried out successfully, and, although confined to the two hills in question—Dipa and Nari by name—afforded valuable results, enabling a large amount of line-cutting to be avoided which would have been necessary had the triangulation been restricted to the plains. Topographical sketches were also obtained of about 100 square miles of plain country and 300 square miles of hills, hitherto unsurveyed.

(14.) Much heavy work was necessary in clearing the rays, and, as in many cases the lines led through tea-estates, great care was required to spare valuable trees and avoid liability for compensation. Lieutenant Harman remarks that Mr. O'Sullivan, who did most of the clearing, deserves credit for his economy in this respect; very lofty signalling scaffoldings were occasionally employed. The weather was frequently very unfavourable for observing, or indeed for field-work of any kind, as there were many days of incessant rains, which not only flooded the nullahs and turned the forest-paths into streams of mud and water, but brought out myriads of leeches which caused the greatest annoyance. Much cane-jungle was met with at times, which is difficult to break through even with elephants, and causes very slow travelling in the case of bare-legged natives. On one occasion a large cargo-boat belonging to the party was swamped in a storm on the river Dihang, and, although recovered once, was swept away again, and sank finally. A case of records which went down with the boat was fortunately recovered by a Miri with a spear.

(15.) Lieutenant Harman mentions meeting with magnificent specimens of rubber trees, which sometimes caused great delay when it was necessary to fell them. One of these trees, which was on the top of a forest-clad hill, was of much use, as it afforded the means of obtaining a station at a height of 112 feet above the ground, for the purpose of connecting Lieutenant Harman's triangulation with that of Lieutenant Woodthorpe, R.E., who was carrying on a topographical survey in the neighbourhood.

(16.) The work of the season comprised the final observations of 19 triangles, extending over a distance of 53 miles, along the banks of the Brahmaputra river to within a few mil[illegible]f Sadiya; the sides being made short in order to minimize the difficulties of line-cutting, the area covered was only 240 square miles; 125 miles of new rays were opened, and 16 stations built in this triangulation. On the secondary series, "Dibrugarh-Jaipur," 3 triangles were completed, which embrace 75 square miles and entailed 63 miles of ray clearing. The positions of 110 peaks on the surrounding hill-ranges have been fixed by intersections, and the heights of 92 of these peaks were determined.

(17.) The health of the party was generally good. Lieutenant Harman himself, however, suffered from a slight sunstroke at one time, and towards the end of the season he was thoroughly knocked up and became very ill. He would then have had to take leave of absence on medical certificate, but that I summoned him to the Head Quarters at Mussooree. Here he completed a considerable portion of the computations connected with the work of the previous field-season, and prepared various programmes for geographical explorations in connection with the work of the next season, which were successively submitted for the consideration of the Government of India and the Chief Commissioner of Assam. Before final orders were passed, it was necessary for him to go to Simla, to explain matters in person to the Foreign Department. The programme sanctioned will, I trust, lead to a considerable increase of our knowledge of the hitherto unexplored regions bordering the Upper Assam Valley.

No. III.—TRIGONOMETRICAL.

THE SECONDARY TRIANGULATION IN BURMAH.

PERSONNEL.

Mr. W. G. Beverley, Officiating Assistant Superintendent, 1st Grade.
" J. Low, Surveyor, 2nd Grade.
" J. W. Mitchell, Surveyor, 4th Grade.
" D. J. Collins, Assistant Surveyor, 4th Grade.

(18.) The state of these operations at the commencement of the season was as follows. Three series of secondary triangulation had been partially carried out, and stations had been chosen for part of a fourth. These were—(1) the series from Myanong to Cape Negrais; (2) the one from Prome to Thayetmyo and Tonghu; (3) the one from Rangoon along the coast, westwards; and (4) a chain of triangulation nearly on the meridian of Tonghu, intended to meet the second of the above in the neighbourhood of Tonghu.

(19.) These secondary chains of triangles all emanate from the principal triangulation of the Eastern Frontier Series, and were projected with the following objects. No. 1 to fix the position of Cape Negrais and the Alguada lighthouse, while it would enable the town of Henzada, and the civil station of Bassein near which it passes, to be laid down. It was carried forward 36 miles in a direct line during the season, through a very difficult country, leaving about 80 miles remaining to be done. No. 2 is to determine the positions of the stations of Prome, Thayetmyo, and Tonghu; besides which, it will, when completed in conjunction with No. 4, fill-in a bend of the frontier which the main triangulation could not follow. Early in March it had been nearly completed for a distance of about 44 miles by Mr. Low; while of the fourth, about 56 miles were completed by Mr. Mitchell, some of the stations visited by the latter having been previously chosen. There then remained a gap of only about 50 miles between the two, which Mr. Beverley considered could be completed by Mr. Low during the rest of the season, so he recalled Mr. Mitchell for work elsewhere. Unfortunately Mr. Low just at that time fell sick, and was obliged to take leave of absence; and, although he returned to duty after a few weeks' absence, he was unable to do much more triangulation, and consequently the gap still remains to be filled up. The 3rd series is intended to determine the position of the Krishna Shoal light; but, through various causes, this was not carried out, which is perhaps the less to be regretted as, during the monsoon succeeding the field-season, that light was destroyed, and it is highly improbable that the new one which is intended to be built will be in exactly the same position. About 70 miles of this triangulation remains to be done.

(20.) The operations generally were carried on through most difficult country, the hills met with being flat-topped, densely wooded, and without any characteristic features to distinguish one from another. The difficulty of obtaining labourers was also very great, as the country is sparsely inhabited, and the Burmese coolies object strongly to being absent from home for more than a day or two Each of the officers of the party suffered much in health. The postal communications were very irregular and unsatisfactory. The out-turn of work was much affected by these causes, and falls short of the average; but the surveyors appear to have worked zealously and well. It would perhaps have been more judicious on the part of Mr. W. G. Beverley, who was in command, to have secured the completion of Messrs. Low and Mitchell's triangulation before removing the latter; but he could not have foreseen Mr. Low's illness, which upset his arrangements.

(21.) On 18th May, Mr. W. G. Beverley obtained furlough for eight months, and the charge of the party was made over to Mr. H. Beverley, by whom the recess duties were carried on, and the report for the year was submitted.

No. IV.—TRIGONOMETRICAL.

THE EASTERN FRONTIER SERIES, MOULMEIN.

PERSONNEL.

Captain J. Hill, R.E., Assistant Superintendent, 1st Grade.
Mr. H. Beverley, Surveyor, 1st Grade.
„ J. C. Clansey, Assistant Surveyor, 3rd Grade.
„ J. O. Hughes, „ „ „

(22.) On the retirement of Mr. Rossenrode, which took place on the 1st November 1876, as was duly noticed in the last report, the charge of the series was temporarily entrusted to Mr. H. Beverley, pending the arrival of Captain J. Hill, R.E., on his return from furlough. Captain Hill did not reach the party until the 16th March; consequently all the arrangements for the field-season, and nearly all the actual operations, were carried out by Mr. H. Beverley, and under his orders; indeed, the programme of the season was so nearly completed when Captain Hill joined, that he judged it best to allow Mr. Beverley to finish the principal triangulation.

(23.) The out-turn of the season comprises the completion of a compound figure round Yebudoung H. S., which was partly observed during the preceding season, and the execution of one hexagon and two quadrilaterals in continuation to the south, bringing the triangulation down to the parallel of 14° in latitude. Twelve stations were visited, affording 17 triangles which cover an aggregate area of 2,032 square miles, and carry the series forward over a distance of 92 miles. The approximate series was carried 56 miles, leaving a hexagon in advance of the completed principal triangulation in readiness for next season's opening observations. As regards secondary triangulation, the state of the atmosphere prevented the determination of "The Three Pagodas"—an important boundary-mark between Siam and Tenasserim—which is to be regretted. The town of Yeh, and two others, being the only ones of any importance which were met with, were laid down.

(24.) The country is a difficult one to triangulate, being forest-clad, almost destitute of roads, and very thinly populated. Many miles of pathway had to be cut by the men of the establishment, and long detours were sometimes necessary between stations; for instance, in one case a direct distance of 18 miles necessitated a circuitous march of 80 miles. The sparseness of population necessitated special arrangements to secure instrument-carriers and labourers, and also to provide food for the establishment. Mr. Beverley appears to have shown good judgment in his arrangements, and energy in the execution of his work; and the results do him much credit.

(25.) The operations of the field-season were brought to a close under Captain Hill's directions, on the 24th April, when the party left Tavoy and proceeded to Moulmein for recess quarters. The party was fortunate in being nearly free from sickness throughout the season, although cholera and small-pox were prevalent in some of the villages visited.

(26.) This triangulation has now reached the parallel of Bangkok, the capital of Siam, and a chain of triangles of little more than 100 miles in length will suffice to connect that important city with the triangulation of India. The distance from Tavoy to Bangkok by sea being over 2,000 miles, it is obvious that a direct trigonometrical connection will be of great value to check and rectify the Marine Surveys which have been carried along the coast-lines. The Government of Siam has therefore been invited to allow of the execution of the proposed chain of triangles.

No. V.—TRIGONOMETRICAL.

THE EASTERN SIND SERIES, MERIDAN 70°.

PERSONNEL.

Captain M. W. Rogers, R.E., Officiating Deputy Superintendent, 3rd Grade.
Mr. W. C. Price, Surveyor, 4th Grade.
" C. P. Torrens, Assistant Surveyor, 3rd Grade.
" P. F. Prunty, " " 4th "

(27.) It was stated in the last report that Captain Rogers, having completed the Jodhpur Series on the meridian of 72½°, took up the Eastern Sind Series, 2½° of longitude to the west, and prepared a large number of principal stations for the final observations. In the season now under review, these observations have been completed at 28 stations, affording 32 triangles arranged in six figures, *viz.*, four hexagons and two quadrilaterals. The series has been carried forward over a distance of 125 miles on the prescribed meridian, and embraces an area of 2,455 square miles. Stations have also been chosen and prepared for a distance of 98 miles in advance of the final observations. The nature of the country does not give much scope for secondary triangulation; but this part of the work was not neglected, and the positions of a number of revenue survey stations and boundary-pillars were determined. Captain Rogers worked energetically and well, and he reports that he was well seconded by his assistants.

(28.) The country passed through was generally a desert, of a worse description than that met with in former seasons on the Jodhpur Series, which has been described in former reports. It is composed for the most part of parallel ridges of sand, of considerable height, and with steep slopes covered with low thorn-jungle. Marching through such country, when the direction of the march can be in no way altered to suit the lie of the sandhills, is most tedious work. Captain Rogers describes the curious formations, known as "Draens," which occasionally occur in this desert. These are tracts of many miles in extent, where the regular sandhills disappear, and give place to a variously-moulded surface of continually shifting sand, utterly devoid of vegetation. These draens are seldom crossed by the natives, and when the survey-party was forced to cross one, careful preparations had to be made in the first instance, and the progress was very slow, five miles proving to be a fatiguing march. It is a remarkable fact that occasionally wells are found in small patches of hard soil in the midst of these wastes of sand, and that the water in such wells is invariably good, though everywhere else it is scarcely drinkable. In fact, to obtain potable water in this region is a constant difficulty, one district of about 30 by 40 miles being reported as altogether without that necessary of life.

No. VI.—TOPOGRAPHICAL.

THE SURVEY OF KATTYWAR.

PERSONNEL.

Major A. Pullan, S.C., Officiating Deputy Superintendent, 3rd Grade.
J. McGill, Esq., Officiating Assistant Superintendent, 1st Grade.
Mr. F. Bell, Surveyor, 3rd Grade.
" N. C. Gwynne, Surveyor, 4th Grade.
" W. A. Fielding, Assistant Surveyor, 2nd Grade.
" G. T. Hall, " " 3rd "
" H. Corkery, " " 4th "
" J. Keating, " " 4th "
Visaji Ragonath Gadboli, Head Sub-Surveyor; and
Ten other Sub-Surveyors.

(29.) Major Pullan has been carrying on this survey, but with a smaller staff of assistants than he had last year, which has necessarily reduced his out-turn of work as compared with the previous season. This will be seen by the following figures:—

	Season 1875-76.	Season 1876-77.	
Topographical ...	2,253	1,716	square miles.
Trigonometrical...	1,850	2,062	" "
Traverse ...	1,600	752	linear "

(30.) The operations this year were carried on in portions of the Hallar and Soruth divisions of Western Kattywar. The principal towns which came within the area of country surveyed are—in sheet 46, Bhayawadar, Jodhpur, and Dhank; in sheet 47, Upleta, Dhoraji, and Kuntiyana; in sheet 48, Bantwa and Wanthali; and in sheet 50, Virāwal and Patan, which last is remarkable for the ancient and world-known Hindu temple of Somnath, now said to be fast falling to pieces, and requiring some steps to be taken to arrest the progress of decay. The country is generally thickly populated; and it is well watered by several rivers, of which the most noticeable are the Moz, the Bhadar, the Uben, the Harna, and the Ojat—the last a deep stream, which, after pursuing a tortuous course to the west, falls into the Bhadar river close to its mouth at Navi Bandar, on the shore of the Gulf of Cutch.

(31.) During the recess season of 1876, fair maps of four sheets were prepared, each in four sections, on the scale of two inches to a mile, for reduction and publication on the one-inch scale. Reductions of eighteen sheets surveyed in previous seasons were prepared, on the scale of one quarter inch to the mile, for incorporation into the Atlas of India. The out-turn of work of all kinds, both in the field and during the recess, is very creditable to Major Pullan, who was well seconded as usual by Mr. McGill.

(32.) Steps will be taken during the field season which is now progressing to extend the triangulation into Cutch with the view of commencing the topographical survey of that Province.

No. VII.—TOPOGRAPHICAL.

THE SURVEY OF GUZERAT.

(33). Lieutenant-Colonel Haig, R.E., supervised the field operations of this survey until about the middle of March, and then proceeded to Europe on furlough, making over the charge of the party to his Assistant, Lieutenant Gibbs, R.E., by whom the general operations were supervised during the remainder of the field-season and the commencement of the recess. On the 13th June, Captain Carter, R.E., took over the charge from Lieutenant Gibbs, and he has retained it up to the present time.

PERSONNEL.

Lieutenant-Colonel C. T. Haig, R.E., Deputy Superintendent, 2nd Grade.
Captain T. T. Carter, R.E., Deputy Superintendent, 3rd Grade.
Lieutenant J. E. Gibbs, R.E., Officiating Assistant Superintendent, 2nd Grade.

Mr. A. D'Souza,	Surveyor,	1st	Grade.
" A. Christie,	"	4th	"
" C. H. McA. Fee,	"	"	"
" J. Hickie, Assistant	"	2nd	"
" G. D. Cusson,	"	"	"
" S. F. Norman,	"	4th	"
" C. Norman,	"	"	"

SUB-SURVEYORS.

Mr. Ferns,
" George,
Gopal Vishnu,
and
Eighteen Native Sub-Surveyors and Apprentices.

(34.) The out-turn of the work of all descriptions has been very satisfactory. An area of 1,988 square miles was surveyed topographically on the scale of two inches to the mile, the British districts in minute detail for publication on the same scale, the Native States in less detail for publication on the one-inch scale. This area falls in sheets Nos. 15, 28, 29, and 30 of the survey (see the Index chart, opposite page of the Appendix), and is sub-divided between British districts and Native States in the following proportions:—

BRITISH	Kaira Collectorate	342 square miles.
	Surat	204 "
	Panch Māhāls	83 "
NATIVE	Baroda	1,202 "
	Sachin	32 "
	Rewakānta	125 "

The area which was triangulated and traversed in advance for future topography consists of 2,200 square miles, appertaining to sheets Nos. 6, 7, 26 and 27; and 280 square miles for the survey of the forests of the Dangs, sheet 52.

(35.) The following maps were drawn and sent in for publication, *viz.*—three of the sections of sheet 78 and as many of sheet 79, drawn for reproduction on the two-inch scale; and the four sections of each of the following sheets—Nos. 30, 78, 79, 80, 81, and 82, drawn for reduction to the one-inch scale. In addition to this, sections 10 and 12 of sheet 14, on the four-inch scale, were entirely re-drawn, as the maps first drawn were found to be unsuited for photo-zincography; and the proofs of 15 sections of the four-inch survey were examined and corrected after photo-zincography.

(36.) Two of Eckhold's omnimeters, manufactured by Messrs. Elliott Brothers, were employed in running traverses through the Dang forests. These instruments are theodolites which are furnished with an auxiliary appliance for enabling the vertical angle subtended by any object to be measured with great accuracy, whereby, when the height of the object is known, its distance may be readily determined. The usual object is a pole, the exact length of which has been carefully ascertained in the first instance. With the omnimeter and its subtense pole, distances of several hundred yards may be measured over rugged and broken ground, where it would be very difficult or impossible to employ a chain, with a degree of accuracy not materially less than that with which the same distances may be measured over smooth ground with the usual measuring-chains. Besides which, one and the same set of readings to the subtense pole enables both the altitude, and the horizontal distance of the point on which the pole is set up, to be readily determined, with a sufficient degree of accuracy for most practical purposes, provided that the distance between the instrument and the pole does not materially exceed a mile. As theodolites, these instruments were found to be very inferior to those of the same sizes which are ordinarily employed in the operations of this Survey; but for the special purposes for which they were required, they gave better results than had been expected, and they are certainly very useful instruments for carrying a line of traverse over a difficult country where chaining is impossible.

(37.) An interesting account of the chief towns and rivers falling within the area of the year's operations will be found in Lieutenant Gibb's report, at page 21—$_a$ of the Appendix. And I may here observe that the annual reports for 1873-74 and 1874-75 contain valuable papers by that officer on the portions of the Dangs in which he had been operating. This year he had collected rock specimens for the purpose of determining the petrology of portions of the district, and was preparing additional notes on the botany, to be added to in the following year and then published.

(38.) But I grieve to state that, on returning to resume operations at the commencement of the field-season of 1877-78, Lieutenant Gibbs was attacked with cholera, when encamped at a place in the Ahmedabad district, far from medical assistance of any kind; being unconscious of his critical condition, he would not allow his servants to send for the nearest doctor, nor even to inform his friend, Mr. LeMessurier, who was encamped a few miles off, until it was too late. He died on the morning of the 21st November 1877. Though the youngest, he was one of the finest and most valuable of the officers of this Department. Gifted with rare abilities, and with the capacity of turning those abilities to good advantage, full of ardour in the prosecution of his own work, and most willing and anxious to assist others in every way, his death is as much to be regretted in the interests of the public service, and more particularly of this Department where he was so highly appreciated, as it is mourned in the circle of his family and friends.

(39.) Of the nature of the country operated in, Lieutenant-Colonel Haig states in his report (not printed) that, "with the exception of the southern portion of sheet 30, the whole of the country under final survey this season has been thickly wooded and much intersected with tortuous and precipitous ravines and water-courses. This has made the progress slow, though all the European assistants have worked well." Of the mapping, Captain Carter states that "a considerable portion of the drawing of the maps for reproduction [to full scale] is done by Mr. T. A. LeMessurier, who is in charge of the party of the Guzerat Revenue Survey which is attached to this office, with a view to our utilizing the detail shown on the village maps by transferring the same to our two-inch maps of British territory. The surveyor's duty in the field-season is to fix by traverse the tribeta or boundary-marks where three villages meet. These points are then plotted on our plane-tables, and the village boundaries are transferred to the plane-table by proportional compasses adjusted to the tribetas. This work is done by the Revenue Survey establishment on return to Head Quarters. We are fortunate in having an officer of Mr. LeMessurier's acquirements and drawing abilities, who is thus a great help in turning out the fair maps on which we show the details taken from the Revenue Survey."

No. VIII.—TOPOGRAPHICAL.

THE SURVEY OF KUMAON AND GARHWAL.

PERSONNEL.

E. C. Ryall, Esq., Officiating Assistant Superintendent, 2nd Grade.
Mr. J. Peyton, Surveyor, 1st Grade.
" W. Todd, " 2nd "
" T. Kinney, Assistant Surveyor, 1st Grade.
" J. Pocock, " " 3rd "
" R. F. Warwick, " " 4th "
and
Six Native Surveyors.

(40.) After the field-operations of this survey during the season 1874-75 had been completed, only a small area remained to be done, lying at the extreme north-east end of the district. It was thought best to leave the survey in abeyance during the season of 1875-76, with a view to applying the whole strength of the party to the survey of the Dehra Dún district, which was by these means completed in that season. The survey of Kumaon and Garhwál was resumed this year under charge of Mr. E. C. Ryall with the staff detailed in the margin, and I have much satisfaction in being able to report that the whole of the field-work is now complete.

(41.) The field-party consisted of Messrs. Ryall, Peyton, Pocock, and Warwick, and two native sub-surveyors, Mr. Todd remaining at Head Quarters, Dehra Dún, in charge of the mapping office, where he was temporarily assisted by Mr. T. Kinney. Mr. Ryall and party left Almorah for the scene of their work about the middle of April.

(42.) The winter of 1876-77 is reported to have been exceptionally severe in these regions; and the spring and early summer of 1877, up to as late as June, were unusually cold and wet. The start from Almorah, long delayed by heavy rain, was eventually made in fine weather, which proved only a break in the wet, as the rain began again on 17th April and lasted till 8th June. Such weather was very much against the surveyors, the field of whose operations had an average elevation of about 16,000 feet above sea-level, and occasionally rose much higher; thus Mr. Ryall's highest point of observation was 19,600, while Mr. Pocock executed one plane-table section at an average elevation of 19,000 feet. The snow-line was found to be much lower than usual, and the inhabitants of the upper valleys, who move up to the higher pastures during each summer, were detained in their winter homes long beyond the ordinary time. As the surveyors depend on these people for the greater part of their supplies, it was impossible to proceed with the work until they could be persuaded to move, and some delay was experienced on this account. Thus Mr. Ryall did not succeed in getting over the Untar Dhurra pass, which has an elevation of 17,350 feet, until the 3rd June.

(43.) On the 8th Mr. Ryall reached Hundes, a district of Chinese Thibet lying north of Kumaon and Garhwál. He hoped that his arrival before the passes were fairly open would be unnoticed, and would enable him to reach the bank of the Sutlej river, which he proposed to survey along, back to his base in British territory, before the jealousy of European intruders entertained by the natives should interfere with his movements. He was disappointed in the hope of his arrival being unnoticed, as he was met at the very boundary by two natives, who immediately proceeded to report the fact to the officials of the district. Mr. Ryall, however, was fortunate in being able to give reasons for crossing the boundary which were deemed sufficient, so he was permitted to go on with his work. After doing all he could in Hundes, he hastened back to form a connection between the work there and the base on the Unta Dhurra ridge, as well as to observe the third angle at some of the stations in the Milam Valley, which, owing to heavy rain and other causes, had been left unobserved in 1874. When he had done this, he finished the topography of this valley, the entrance into which, through a stupendous gorge about 12 miles in length, overhung by large masses of granite precipices, is described as most formidable. The road consists for the most part of a series of narrow steps built along the faces of steep hillsides or rugged precipices; and, in other parts where this is impracticable, planks leading from one ledge to another are laid across.

(44.) Mr. Peyton was entrusted with the survey of the Byans Valley, which he completed satisfactorily; some notes on his work and the topography of the valley will be found embodied in Mr. Ryall's report. At Garbia, the largest village in the valley, Mr. Peyton noticed that the Tartar physiognomy by no means predominated, and, although the noses were generally somewhat broad and the cheek-bones large and prominent, yet he saw some faces which in any country would be acknowledged to be pretty and expressive.

(45.) The total out-turn of work reflects much credit on Mr. Ryall and his assistants, considering the nature of the ground surveyed. An area of 870 square miles was triangulated for topography, and areas of 959 and of 640 square miles were sketched topographically on the respective scales of half an inch and one inch to the mile. Besides this, a larger number of peaks were fixed in an area of about 13,000 square miles of territory beyond the British frontier, which will be of great value in rectifying and amplifying the existing sketch maps of that region; the additional geographical information thus acquired will, I trust, form the subject of a future Trans-Himalayan exploration report from the pen of Mr. Ryall.

(46.) Mr. Ryall was supplied with four of the new portable mercurial barometers designed by Captain St. George. These barometers have arrangements whereby the tubes can be readily filled with mercury without any considerable admixture of air, so that a practically perfect vacuum may be obtained whenever desired; the tubes are intended to be emptied whenever the instrument has to be transported about, and thus the risk of breakage is very much less than for a barometer carried about, as usual, with its tube full of mercury. The instruments were filled and read at various heights, ranging from 11,000 to 19,000 feet, which had been independently determined by the triangulation; the differential barometric determinations agreed fairly with the trigonometrical as a rule, though there are some startling differences which have not yet been accounted for; the absolute heights were far more frequently in defect than in excess, which tends to show that little air can have got into the tubes during the process of filling them with mercury, and is so far satisfactory. The process of filling is, however, a tedious one, and difficult to accomplish when the fingers are chilled at very high altitudes; but the barometers are strong and portable, and, with moderate care, they may be carried over the most rugged mountain regions without much fear of breakage.

(47.) The operations of the present year have completed the topographical survey of Kumaon and Garhwál, which is a matter of much gratification.

No. IX.—SPIRIT-LEVELLING.

OPERATIONS IN GUZERAT.

PERSONNEL.

Captain A. Baird, R.E., Officiating Assistant Superintendent, 1st Grade.
Mr. T. H. Rendell, Assistant Surveyor, 1st Grade.
Narsing Dass, Sub-Surveyor.

(48.) These operations are under the charge of Captain Baird, R.E., and during season 1875-76 two parties were employed, one directly under Captain Baird himself, and the other under Mr. Rendell. At the end of that field-season, Captain Baird went to England on three months' privilege leave, and was afterwards detained there on duty in connection with the reduction of the tidal observations in the Gulf of Cutch which had been made in the previous year. The levelling operations now under report were consequently confined to one party under Mr. Rendell, working on instructions drawn up by Captain Baird before proceeding on leave.

(49.) They comprise 358¼ miles, carried out on the usual rigorous system of this Department, by two observers working independently and checking each other station by station. Of this, 183½ miles was a part of the main line, between the Gulf of Cutch and Bombay, commencing a little below Ahmedabad and running south through Broach and Surat down to Damaun railway station, where it was closed for the season. The remaining 174¾ miles are distributed in branch lines connecting important places *en route*, such as Cambay, and places along the railway of His Highness the Guicowar to Dabhei, and along the branch line of the Bombay, Baroda, and Central India Railway from Anand to Pali.

(50.) The heights of 306 permanent bench-marks were determined, several of which were also points of the Railway and the Irrigation systems of levelling, which have thus been connected together and referred to the same datum as that of the Survey Department. The value of such checks is proved by several cases of discrepancy which were discovered by Captain Baird. The out-turn of work is satisfactory, both as respects quantity and quality, and is very creditable to Mr. Rendell.

No. X.—TIDAL INVESTIGATIONS.

ANALYSIS OF OBSERVATIONS AT TIDAL STATIONS IN THE GULF OF CUTCH AND AT TUTICORIN.

(51.) In previous reports I have given the history of these operations, and described the several steps which have been taken in order to obtain continuous registers of the momentarily varying changes in the sea-level, at the points on the coasts of the Gulf of Cutch, and at Tuticorin, where tidal stations had been erected. The observations also included continuous registers of the barometric pressure, and of the velocity and direction of the wind, which were taken by self-recording instruments at each station *pari passu* with the tidal registers. When all the observations were completed, the ordinates of the several curves were measured, (taking full account of clock error whenever there was any) and then tabulated for each hour of every day. The numerical results thus obtained serve as the data on which the analysis of the observations was subsequently based.

(52.) This analysis, I felt assured, would be best performed with the assistance and co-operation of Mr. Roberts, of the Nautical Almanac Office in London, by whom all the tidal observations taken for the British Association had been, and are still being, reduced and analyzed, under the superintendence of Sir William Thomson. I therefore obtained sanction for Captain Baird to remain in England, and reduce his observations with Mr. Roberts' assistance. The results will be presently stated. But first it is necessary to give a brief epitome of the method of investigation which has been followed, and which is described in detail in the notes on the Harmonic Analysis of Tidal Observations, London, 1872, and in various numbers of the proceedings of the British Association.

(53.) The rise and fall of the level of the ocean, twice, or nearly so, in twenty-four hours, is well known to be due to the attractions of the sun and the moon. If the orbit of the earth and that of the moon were quite circular and lay in the plane of the equator, and if the moon performed its revolution round the earth in the same time that the sun appears to revolve around the earth, then there would be two tides daily, differing from each other in form—should the sun and moon not be in conjunction—but recurring alike from day to day. The moon, however, makes her circuit of the earth in 48 minutes over the twenty-four hours and thus the sun makes thirty apparent circuits of the earth while the moon is only making twenty-nine; moreover, the orbits of the earth and of the moon are not circular, nor are they situated in the plane of the equator. Thus the positions of the sun and moon, relatively to the earth, are momentarily varying in distance, declination, and right ascension. Consequently, the level of the ocean is subject to momentary variations in the dynamical action of the disturbing bodies; and these cause a variety of tides which recur periodically, some in short, others in long, periods.

(54.) In the present investigations, the short and the long period tides have been analyzed by different methods. The former—which here embrace all tides recurring in periods of or about a day in duration, and in any aliquot part of the *quasi*-diurnal period—have been treated in accordance with the synthesis of Laplace. Thus a number of fictitious stars are assumed to move, each uniformly in the plane of the earth's equator, with angular velocities which are small in comparison with that of the earth's rotation, so that the period of each is something not very different from 24 mean solar hours. Each star is supposed to produce a primary tide in its *quasi*-diurnal period, and also various sub-tides which run through their periods respectively twice, three times, or oftener during the primary period; some of the stars, however, do not produce a full-period tide, but only sub-tides in the sub-periods.

(55.) The portion of the height of the sea-level above or below its mean height (with reference to some fixed datum line), which is due to the combined influences of the several tides produced by any one of the fictitious stars, is given by the following well-known expression of the law of periodicity:—

$$h = R_1 \cos(nt - \epsilon_1) + R_2 \cos(2nt - \epsilon_2) + R_3 \cos(3nt - \epsilon_3) + \dots$$

in which h is the height above mean sea at any moment, t is the time expressed in mean solar hours, commencing at 0^h astronomical reckoning, and n is the angular velocity of the star in degrees of arc per mean solar hour, so that $360° \div n$ denotes the period of the star in hours of mean time. R_1 is the amplitude, and ϵ_1 the epoch of the full-period tide; R_2 and ϵ_2, R_3 and ϵ_3, &c., are the amplitudes and epochs of the sub-tides, whose periods are one-half, one-third, &c., that of the primary period. The amplitude is the semi-diameter of the circle whose circumference indicates the path of a tide. The epoch is the arc which, when divided by the angular velocity of the tide, gives the hour angle when the height of the tide is a maximum; this occurs, on the day of starting, when $nt = \epsilon_1$ for a primary tide, when $2nt = \epsilon_2$ (and again 12 *quasi*-hours afterwards) for a tide whose period is half that of the primary, and so on.

(56.) Thus, if we now put h for the height of the sea-level at any moment, and A for the value of the height of the mean sea-level which results from the combined influnce of the whole of the fictitious stars, we have—

$$h = A + \Sigma \{R_1 \cos(nt - \epsilon_1) + R_2 \cos(2nt - \epsilon_2) + \quad . \quad . \quad . \}$$

where the symbol Σ stands for the summation of the whole of the terms within the brackets which relate to all the fictitious stars.

(57.) There are two principal stars, respectively called S and M for brevity, the first of which represents the mean sun, or that point in the plane of the earth's equator whose hour-angle is equal to mean solar time; the second represents the mean moon, a point moving in the plane of the equator with an angular velocity equal to the mean angular velocity of the moon. The other fictitious stars respectively furnish the corrections to S and M for declination and parallax, to M for lunar evection and variation, and to S and M for the compound actions which produce what are called Helmholtz Tides, &c. The 24th part of the period of star S being an hour, that of any other of the fictitious stars may be conveniently spoken of, and is here called a *quasi*-hour.

(58.) To find the argument (the angular velocity n of the preceding formulæ) for each fictitious star, various combinations have to be made of the following fundamental angular velocities, *viz.* :—

γ, the earth's rotation	$=15°\cdot0410686$	per mean solar hour.
σ, the moon's revolution round the earth ...	$= 0\cdot5490165$	,, ,,
μ, the earth's revolution round the sun ..	$= 0\cdot0410686$	,, ,,
ϖ, the progression of the moon's perigee...	$= 0\cdot0046418$	,, ,,

The several fictitious stars whose tides have been analyzed in these investigations are—

S,	with argument $n =$	$\gamma - \eta$	$= 15°\cdot$
M	,,	$\gamma - \sigma$	$= 14\cdot4920521$
K	,,	γ	$= 15\cdot0410686$
O	,,	$\gamma - 2\sigma$	$= 13\cdot9430356$
P	,,	$\gamma - 2\eta$	$= 14\cdot9589314$
J	,,	$\gamma + \sigma - \varpi$	$= 15\cdot5854433$
Q	,,	$\gamma - 3\sigma + \varpi$	$= 13\cdot3986609$
μ	,,	$\gamma - 2\sigma + \eta$	$= 13\cdot9841042$
N	,,	$\gamma - \frac{3}{2}\sigma + \frac{1}{2}\varpi$	$= 14\cdot2198648$
L	,,	$\gamma - \frac{1}{2}\sigma - \frac{1}{2}\varpi$	$= 14\cdot7642394$
ν	,,	$\gamma - \frac{3}{2}\sigma - \frac{1}{2}\varpi + \eta$	$= 14\cdot2562915$
λ	,,	$\gamma - \frac{1}{2}\sigma + \frac{1}{2}\varpi - \eta$	$= 14\cdot7278127$
MS	,,	$\gamma - \frac{1}{2}\sigma - \frac{1}{2}\eta$	$= 14\cdot7460261$
and SM	,,	$\gamma + \sigma - 2\eta$	$= 15\cdot5079479$

(59.) The *quasi*-hour angles of the several fictitious stars, other than S, at mean noon of the day of starting, were found by putting

$\gamma =$ the Sidereal time,
$\eta =$ the Sun's mean longitude $= \gamma$,
$\sigma =$ the Moon's mean longitude,
$\sigma - \tilde{\omega} =$ the Moon's mean anomaly,

and taking the corresponding numerical values of each element for the hour and station from the Nautical Almanac and Hansen's Lunar Tables, and then substituting these values in the preceding symbolic expressions for the hourly variations of the several stars.

(60.) The number of stars and the angular velocity of each star having thus been decided on, *a priori*, from theoretical considerations, the values of the constants R and ϵ for the tidal constituents of each star have to be determined from the evidence afforded by the tabulated values of the height of the sea-level for every hour of the day during the entire period of observation, which should not be less than 371 days. The values of the constants have been computed for the several tides at the three stations of Okha, Nowanár, and Hanstal, and are given below. It will be remembered (see Section XI of my Report for 1874-75) that Okha is situated at the entrance to the Gulf of Cutch, Nowanár midway up the Gulf, and Hanstal at its upper extremity; also that continuous observations over a period of not less than 14 months were obtained at the upper and lower stations, whereas at the middle station, Nowanár, there was a break of several months, in consequence of an alteration of the foreshore during the monsoon of 1874; thus the results for Nowanár are far from being as exact and complete as those for the two other stations.

Table of the Constants.

	Okha.	Nowanár.	Hanstal.
	Feet. °	Feet. °	Feet. °
The star S ...	$R_1 = 0{\cdot}0741, \epsilon_1 = 149{\cdot}89$	Wanting.	$R_1 = 0{\cdot}1292, \epsilon_1 = 164{\cdot}01$
	$R_2 = 1{\cdot}2224, \epsilon_2 = 14{\cdot}37$	$R_2 - 1{\cdot}8933, \epsilon_2 = 55{\cdot}33$	$R_2 = 1{\cdot}9277, \epsilon_2 = 84{\cdot}51$
	$R_4 = 0{\cdot}0132, \epsilon_4 = 116{\cdot}57$	$R_4 = 0{\cdot}0131, \epsilon_4 = 359{\cdot}56$	$R_4 = 0{\cdot}0211, \epsilon_4 = 61{\cdot}74$
	$R_6 = 0{\cdot}0030, \epsilon_6 = 20{\cdot}92$	Wanting.	$R_6 = 0{\cdot}0069, \epsilon_6 = 166{\cdot}57$
	$R_8 = 0{\cdot}0006, \epsilon_8 = 219{\cdot}81$	Ditto.	$R_8 = 0{\cdot}0025, \epsilon_8 = 158{\cdot}63$
The star M ...	$R_1 = 0{\cdot}1122, \epsilon_1 = 120{\cdot}86$	Ditto.	$R_1 = 0{\cdot}1208, \epsilon_1 = 155{\cdot}61$
	$R_2 = 3{\cdot}6936, \epsilon_2 = 348{\cdot}08$	$R_2 = 5{\cdot}8448, \epsilon_2 = 25{\cdot}32$	$R_2 = 6{\cdot}6291, \epsilon_2 = 46{\cdot}52$
	$R_3 = 0{\cdot}0289, \epsilon_3 = 22{\cdot}10$	Wanting.	$R_3 = 0{\cdot}0534, \epsilon_3 = 93{\cdot}55$
	$R_4 = 0{\cdot}1265, \epsilon_4 = 108{\cdot}88$	$R_4 = 0{\cdot}1023, \epsilon_4 = 275{\cdot}00$	$R_4 = 0{\cdot}6803, \epsilon_4 = 331{\cdot}55$
	$R_6 = 0{\cdot}0056, \epsilon_6 = 272{\cdot}57$	Wanting.	$R_6 = 0{\cdot}2760, \epsilon_6 = 248{\cdot}94$
	$R_8 = 0{\cdot}0102, \epsilon_8 = 100{\cdot}06$	Ditto.	$R_8 = 0{\cdot}0726, \epsilon_8 = 154{\cdot}36$
The star K ...	$R_1 = 1{\cdot}5605, \epsilon_1 = 146{\cdot}60$	$R_1 = 1{\cdot}6857, \epsilon_1 = 156{\cdot}00$	$R_1 = 1{\cdot}6502, \epsilon_1 = 174{\cdot}60$
	$R_2 = 0{\cdot}4207, \epsilon_2 = 24{\cdot}82$	$R_2 = 0{\cdot}4780, \epsilon_2 = 76{\cdot}11$	$R_2 = 0{\cdot}6767, \epsilon_2 = 88{\cdot}63$
The star O ...	$R_1 = 0{\cdot}8095, \epsilon_1 = 322{\cdot}67$	$R_1 = 0{\cdot}7987, \epsilon_1 = 332{\cdot}04$	$R_1 = 0{\cdot}8807, \epsilon_1 = 340{\cdot}76$
The star P ...	$R_1 = 0{\cdot}3844, \epsilon_1 = 319{\cdot}94$	$R_1 = 0{\cdot}2806, \epsilon_1 = 342{\cdot}02$	$R_1 = 0{\cdot}3839, \epsilon_1 = 353{\cdot}65$
The star J ...	$R_1 = 0{\cdot}1231, \epsilon_1 = 176{\cdot}32$	$R_1 = 0{\cdot}1698, \epsilon_1 = 191{\cdot}77$	$R_1 - 0{\cdot}1091, \epsilon_1 = 222{\cdot}61$
The star Q ...	$R_1 = 0{\cdot}1596, \epsilon_1 = 324{\cdot}68$	$R_1 = 0{\cdot}1697, \epsilon_1 = 335{\cdot}14$	$R_1 = 0{\cdot}1618, \epsilon_1 = 343{\cdot}23$
The star L ...	$R_2 = 0{\cdot}1511, \epsilon_2 = 224{\cdot}77$	$R_2 = 0{\cdot}3569, \epsilon_2 = 226{\cdot}93$	$R_2 = 0{\cdot}3892, \epsilon_2 = 238{\cdot}32$
The star N ...	$R_2 = 0{\cdot}7551, \epsilon_2 = 322{\cdot}94$	$R_2 = 1{\cdot}2205, \epsilon_2 = 11{\cdot}72$	$R_2 = 1{\cdot}1535, \epsilon = 26{\cdot}76$
The star λ ...	$R_2 = 0{\cdot}0712, \epsilon_2 = 204{\cdot}40$	$R = 0{\cdot}1466, \epsilon_2 = 251{\cdot}10$	$R^2 = 0{\cdot}2268, \epsilon = 219{\cdot}57$
The star ν ...	$R_2 = 0{\cdot}1592, \epsilon_2 = 8{\cdot}50$	$R = 0{\cdot}2975, \epsilon_2 = 5{\cdot}43$	$R_2 = 0{\cdot}2864, \epsilon_2 = 48{\cdot}24$
The star μ ...	$R_2 = 0{\cdot}1896, \epsilon_2 = 184{\cdot}26$	$R = 0{\cdot}4026, \epsilon_2 = 186{\cdot}44$	$R_2 = 0{\cdot}5569, \epsilon = 179{\cdot}74$
The star SM ...	$R_2 = 0{\cdot}0435, \epsilon_2 = 291{\cdot}24$	Wanting.	$R_2 = 0{\cdot}1309, \epsilon 2 = 297{\cdot}74$
The star MS ...	$R_4 = 0{\cdot}0619, \epsilon_4 = 112{\cdot}37$	Ditto.	$R_4 = 0{\cdot}3388, \epsilon_4 = 13{\cdot}01$

(61.) It will be seen that the principal tides are first the *quasi*-semi-diurnal of M, and then the semi-diurnal of S and the *quasi*-diurnal of K, which range from one-third to one-fourth of the former. S and M being the principal stars, their sub-tides, down to the three hourly tide of S and the corresponding tide of M, have been computed. For K the *quasi*-diurnal and semi-diurnal tides were computed; for the stars O to Q only the primary tides. For the stars L to SM there are no primaries, and the tides of longest period are the *quasi*-semi-diurnal; for MS the longest tide is the *quasi*-demi-semi-diurnal; these, being the principal ones for each star, have been computed.

(62.) Here it is necessary to observe that the number of sub-tides which have to be investigated in each instance, in order to evaluate the full influence of the star, is a matter which can only be decided after considerable experience of such investigations has been gained by the analysis of the tides at a great variety of stations. It was therefore left to Mr. Roberts, whose practical familiarity with the subject probably exceeds that of any other individual, to prescribe the number of terms to be computed for each star.

(63.) On inserting the numerical values of the constants R and ϵ in the general expression, and substituting for nt its values in succession for every hour from the starting-point, the height (in feet) of each tide and sub-tide may be computed for every hour. The sum of these gives the portion of the height of the sea-level at that hour which is due to the influence of the short-period tides. This usually far exceeds the portion which is due to all other causes, and is thus frequently taken to represent the whole height.

(64.) Should it be desired to compute the hourly heights for any day of any year, without commencing at the starting-point of the observations, as may be necessary when tidal predictions are required, the values of γ, η, σ, and $\bar{\omega}$ must be found, as in paragraph (59), for mean noon of the day which may be adopted as the new starting-point; the *quasi*-hour-angles of the several fictitious stars, other than S, at that moment must then be found, after which those for the succeeding hours may be obtained by successive additions of the respective hourly increments which are due to each star.

(65.) The values of the constants R and ϵ having been determined for each of the three tidal stations, the next step taken was the calculation of the height of the sea-level at each hour, throughout the entire period of registration at each station. The differences between the observed and the computed values were then taken as the data for calculating the influence of variations in barometric pressure, and in the velocity and direction of the wind, on the sea-level. Equations were formed in which the unknown quantities were B, the effect of a barometric pressure of one inch, and N and E, the effects of the North and the East components respectively of winds blowing at the rate of 10 miles an hour. Of these equations there were as many as the number of days of observation; they were solved by the method of minimum squares. Corrections were then computed for the daily variations of the atmospheric influences on the sea-level, and were applied to the values of height resulting from the previous investigations of the short-period tides. Finally, the differences between the heights thus determined and those actually observed were taken as the data for calculating the influence of each of the long-period tides.

(66.) The evaluation of the atmospheric influences gave the following factors for changes of sea-level due to a barometric pressure of one inch, and to north and east winds travelling with a velocity of 10 miles per hour:—

	At Okha.	At Hanstal.
Barometric pressure	+ 0·356 feet	— 0·438 feet.
North Wind	— 0·191 ,,	— 0·262 ,,
East Wind	+ 0·161 ,,	+ 0·087 ,,

These results are not satisfactory; the height of the sea-level at Okha appears to increase with an increase of barometric pressure, which is scarcely possible. It happens that at this station the changes of pressure occurred, as a rule, simultaneously with the changes of wind; and thus it is impossible to determine the separate effect of each, otherwise than by some arbitrary method of treatment. The observations will therefore be again analyzed, with a view to ascertaining whether they may not be made to yield more consistent results. Meanwhile, the values of the atmospheric factors already obtained must be considered to be only approximate, giving fairly accurate results when employed collectively but not individually.

(67.) Of the constants for the long-period tides the following values have been computed for the stations of Okha and Hanstal, after the elimination of atmospheric influences by employing the preliminary values of the factors which are given in the preceding paragraph. At Nowanár sufficient observations are not forthcoming for the evaluation of either the atmospheric or the long-period tides.

Long-period tides, and their Constants.

$(\sigma - \bar{\omega})$ Lunar monthly elliptic tide,
2σ Lunar fortnightly declinational tide,
$2(\sigma - \eta)$ Luni-solar synodic fortnightly tide,
η Solar annual elliptic tide,
2η Solar semi-annual declinational tide,

Okha. Feet. °	Tide.	Hanstal. Feet. °
R=0·058, ϵ=311·38	$(\sigma - \bar{\omega})$	R=0·107, ϵ= 14·17
„ 0·070, „ 52·73	2σ	„ 0·142, „ 45·74
„ 0·136, „ 249·19	$2(\sigma - \eta)$	„ 0·163, „ 11·76
„ 0·162, „ 3·11	η	„ 0·024, „ 195·32
„ 0·121, „ 144·75	2η	„ 0·090, „ 156·38

(68.) The present appears to be a good opportunity for giving the tidal constituents which were calculated by Mr. Roberts for the Port of Tuticorin, from observations taken there in the year 1871-72, by Captain Branfill, with a self-registering tide-gauge similar to those employed in the Gulf of Cutch.

Short-period tides at Tuticorin, and their Constants.

Tide	Feet. °	Tide	Feet. °
Star S	R_1=0·039, ϵ_1=108·78	Star P	R_1=0·064, ϵ_1=281·78
	R_2=0·429, ϵ_2= 95·59	„ J	R_1=0·011, ϵ_1=181·70
	R_4=0·073, ϵ_4=282·65	„ K	R_1=0·274, ϵ_1=132·80
	R_6=0·003, ϵ_6= 51·34		R_2=0·143, ϵ_2=116·25
	R_8=0·007, ϵ_8=262·75	„ Q	R_1=0·032, ϵ_2=359·08
Star M	R_1=0·006, ϵ_1=234·64	„ L	R_2=0·030, ϵ_2=242·50
	R_2=0·596, ϵ_2= 55·81	„ N	R_2=0·072, ϵ_2=38·69
	R_3=0·015, ϵ_3=182·86	Star λ	R_2=0·019, ϵ_2=248·45
	R_4=0·022, ϵ_4=192·76	„ ν	R_2=0·022, ϵ_2=35·58
	R_6=0·010, ϵ_6= 45·91	„ μ	R_2=0·016, ϵ_2=183·83
	R_8=0·004, ϵ_8=319·74	„ 2SM	R_2=0·011, ϵ_2=246·37
Star O	R_1=0·112, ϵ_1=314·25	„ MS	R_4=0·018, ϵ_4=282·99

Long-period tides at Tuticorin, and their Constants.

	Feet.	°
Lunar monthly ...	R=0·024	ϵ=313·15
Lunar fortnightly ...	„ 0·065	„ 69·54
Luni-solar fortnightly...	„ 0·016	„ 307·85
Solar annual ...	„ 0·399	„ 313·35
Solar semi-annual ...	„ 0·080	„ 87·50

Here there were no data for evaluating the atmospheric tides separately, and it is probable that the magnitude of the amplitude of the solar annual tide is in great measure due to atmospheric influences.

No. XI.—TIDAL INVESTIGATIONS.

PROGRAMME OF FUTURE OPERATIONS.

(69.) The following important orders on the systematic record of tidal observations at selected points on the Coasts of India, were issued by the Government of India in the Department of Revenue, Agriculture, and Commerce, under date 4th July 1877:—

The Governor General in Council observes that the great scientific advantages of a systematic record of tidal observations on Indian coasts have frequently been urged upon, and admitted by, the Government of India. Hitherto the efforts in the direction of such a record have been desultory and in many cases wanting in intelligent guidance and careful selection of the points where the observations should be recorded. Additional importance has recently been given to the subject by the institution of a Marine Survey Department, for whose operations accurate tidal observations are a necessity without which no permanent record of the changes of ground in the different harbours of the coast can be kept up.

2. The advantages to be expected from well-considered and carefully conducted observations of the tides are mainly the following:—

(1) They enable standards to be fixed for the purposes of survey.

(2) They afford data for the calculation of the rise and fall of the tides, and thus subserve the purposes of navigation.

(3) They are of scientific interest apart from their practical usefulness as stated above.

The first two of these advantages are of strictly local bearing: an accurate survey of a port is essential to the safety of the shipping frequenting it, and correct tide-tables are necessary for the convenience of navigators and for engineering purposes within the port itself.

3. The Governor General in Council is of opinion that, in view of these considerations, every port where a tide-gauge is set up should pay for its establishment and maintenance from port funds. The third object, the scientific results to be expected from the record, will be sufficiently provided for by the appointment by the Government of India of one of its own officers to supervise and control the local observations, and to arrange for their utilization to the utmost extent possible. The charges will thus be divided in a manner appropriate to the advantages to be secured.

4. His Excellency in Council accordingly resolves to entrust the general superintendence and control of tidal observations upon Indian coasts to Captain Baird, R.E., Deputy Superintendent in the Great Trigonometrical Survey Department, who will be guided in his operations by the orders and advice of the head of that Department. This will involve no new charge upon Imperial Funds, for Captain Baird has for some years past been engaged upon observations of this nature in the Gulf of Cutch and in reduction of the observations in England: the work is of a nature which properly falls within the scope of the operations of the Great Trigonometrical Survey; and the object of the present change is merely to provide for its extension and systematization under an undivided control. Captain Baird will thus remain a member of the Department, and his operations will form one of the subjects to be treated by the Superintendent in his annual report.

5. The first duty of the Superintendent will be to instruct Captain Baird to determine, in communication with the Governments of the maritime provinces, the points where observations should be carried out. The necessary gauges (where these do not already exist) will then have to be provided from port funds, and the establishments entertained under the sanction of the Local Governments. It will probably be most convenient that all Captain Baird's communications with the establishments in charge should pass through the Local Governments, but this point may be settled as may be found most expedient in practice.

(70.) In accordance with these orders, enquiries have been, and are being, made with a view to ascertain the ports at which it will be desirable to establish tidal stations. The suitability of a port for this purpose will depend, *first*, on a site being available thereat, on which a self-registering tide-gauge may be erected, so as to be either immediately over the sea, or connected by piping with the sea at some point where there is a depth of not less than 10 to 15 feet of water at the lowest tides; *secondly*, on the presence of a port officer, who will exercise a general supervision over the operations, and correct the clocks of the several self-registering instruments, whenever necessary, either by direct determinations of time, or by arranging to get the true time from the nearest telegraphic office; *thirdly*, on the feasibility of making arrangements for the periodical inspection of the instruments at intervals of not less than six months generally, and more frequently when no officer is resident on the spot to superintend the operations.

(71.) So far as has yet been ascertained, the ports which seem likely to answer all the required conditions are Aden, Kurrachee, Bombay, Carwar, Beypore, Paumben, Madras, Vizagapatam, Akyab, Rangoon, and Port Blair. The following ports are believed to be unsuitable: Surat, Mangalore, Cannanore, Cochin, Muttrun, Negapatam, Coconada, False Point, Diamond Harbour, Moulmein, and Mergui.

(72.) At Aden a self-registering tide-gauge was erected by the local officers about two years ago; but the registers have been taken in such an unsatisfactory manner that the results are not of the slightest use. Captain Baird is now arranging for the establishment of a tidal station there, with proper instruments, and trained men to take charge of them. At Kurrachee a tide-gauge, which was originally set up by Mr. Parkes, has been in work for several years, and has furnished the data from which tide-tables for the port have been computed annually by Mr. Parkes. In course of time the present gauge—the scale of which is very small—should be replaced by one of those which are used by Captain Baird, and an anemometer and a barometer (both self-registering) should be set up beside the gauge. But it is not desirable to interfere with the working of the present arrangements at Kurrachee until other ports, at which nothing is now being done in the way of tidal observations, are duly provided for. At Bombay, Carwar, and Madras, instruments are now being set up by Captain Baird.

No. XII.—GEODETIC.

ELECTRO-TELEGRAPHIC DETERMINATIONS OF DIFFERENCES OF LONGITUDE IN SOUTHERN INDIA, AND BETWEEN BOMBAY AND SUEZ.

PERSONNEL.

Captain (now Major) W. M. Campbell, R.E., Officiating Deputy Superintendent, 2nd Grade.
" W. J. Heaviside, R.E., Deputy Superintendent, 3rd Grade.
Mr. C. J. Neuville, Surveyor, 2nd Grade.
" E. J. Connor, Assistant Surveyor, 1st Grade.
" J. Bond, " " "

(73.) Measurements of differential longitude, with the aid of the electric-telegraph, were commenced in Southern India in the year 1872-73, when the following arcs between stations of the Great Trigonometrical Survey were measured by Major Herschel and Captain Campbell :—

(1) Madras—Bangalore
(2) Bangalore—Mangalore

They are fully described in my report for that year. Operations were then suspended for two years, and were resumed in 1875-76, when the following arcs were measured by Captains Campbell and Heaviside :—

(3) Hyderabad (Bolarum)—Bombay
(4) Bellary—Bombay
(5) Hyderabad—Bellary
(6) Madras—Hyderabad (Bolarum)
(7) Madras—Bellary
(8) Bangalore—Bellary

(74.) In the present year the following arcs have been measured by Captains Campbell and Heaviside :—

(9) Vizagapatam—Madras
(10) Vizagapatam—Bellary
(11) Mangalore—Bombay

Thus differential determinations of longitude have been completed on eleven arcs between points in Southern India which had already been connected together by the great triangulation, whereby a considerable amount of information has been obtained which is of much value for geodetic requirements.

(75.) When these operations were commenced, I determined that they should be carried on, at least for some time, with great caution, and in such a manner as to be self-verificatory, in order that some more satisfactory estimate might be formed of the magnitudes of the errors to which they are liable, than would be afforded by the theoretical probable errors of the observations. It was evident that the observations might be burthened with various errors—some possibly constant—in the determination of the local times, and also in the transmission of the signals between the stations, and that no estimate could be formed of either the absolute or the relative magnitudes of these errors, unless steps were taken to verify the results by independent processes of operation. The simplest arrangement appeared to be to select three trigonometrical stations, as A, B and C, at nearly equal distances apart, on a telegraph line forming a circuit, and, after having measured the longitudinal arcs corresponding to A B and B C, to measure A C independently as a check on the two first arcs. This is the principle which has been adopted as far as was practicable. The stations have been chosen on the telegraph lines in such a manner as to throw a network of triangles over the face of the country. In a few cases the lines of telegraph run in tolerable proximity to the sides of the triangles thus formed, and furnish an independent line for each side; more frequently, however, a line runs through a triangle, sending off branches to the stations right and left; and it occasionally happens that the wire is wanting on one side, and the electrical connection is made by linking-up the wires on the two other sides. Here this is less of independency as regards the errors involved in the transmission of signals, but the local times are still determined independently, as on a true circuit, and it now appears that this is the point which it is of most importance to secure.

(76.) It had long been questioned whether the errors to which operations of this nature are liable were due in greater measure to the astronomical or to the electrical parts of the observations; but experience has now shown that when there is direct electrical communication between the stations, without the intervention of relays, as has always been the case in our operations, the aggregate of the errors in the signalling between the stations is immaterial in comparison with that of the errors in the determination of the local time by astronomical observations. (See paragraphs 12 and 22 of Captain Campbell's report in the Appendix.) Thus it has been ascertained that the two arcs first measured have suffered to some extent, and are not as valuable as those subsequently measured, because of a defect in the construction of one of the two transit instruments which were employed in the time determinations, and not because of any sensible imperfection in the electric arrangements. This defect, which was known at the time, though its exact locus could not be immediately discovered, was traced home and rectified before any of the subsequent arcs were measured. But even with astronomical instruments which have no sensible defects, the several errors which are liable to obtain in the determination of the times, more particularly those arising from the personal equations of the observers, are found to materially outweigh those which occur in the transmission and receipt of the signals on an uninterrupted line of telegraph.

(77.) With regard to the determination of personal equation, an interesting circumstance was discovered this year, *viz.*, that in observing transits of stars, Captain Campbell's equation, relatively to that of Captain Heaviside, varied according as the star appeared to cross the field of the telescope from right to left or from left to right. Thus the original equation for all stars during the previous year had been

$$C-H = +\overset{s.}{\cdot 064} \pm \overset{s.}{\cdot 006}$$

which it became necessary to replace by two new equations, *viz.*—

$$C-H = +\overset{s.}{\cdot 102} \pm \overset{s.}{\cdot 009} \text{ for stars north of the zenith.}$$

$$C-H = +\overset{s.}{\cdot 041} \pm \overset{s.}{\cdot 003} \quad \text{,,} \quad \text{south} \quad \text{,,} \quad \text{,,}$$

The previous reductions were corrected accordingly, with the effect of bringing the results into still closer harmony than the original values, which are given at page 15 of the report for last year.

(78.) The following table gives the telegraphic and the trigonometrical differences of longitude on each of the arcs:—

	Telegraphic. A		Trigonometrical. B		B—A.
	m.	s.	m.	s.	s.
(1) Madras—Bangalore	10	39·04	10	39·61	+ 0·57
(2) Bangalore—Mangalore	10	56·77	10	57·17	+ 0·40
(3) Hyderabad (Bolarum)—Bombay ...	22	48·85	22	49·52	+ 0·67
(4) Bellary—Bombay	16	26·96	16	27·42	+ 0·46
(5) Hyderabad (Bolarum)—Bellary ...	6	21·88	6	22·10	+ 0·22
(6) Madras—Hyderabad (Bolarum) ...	6	54·69	6	54·81	+ 0·12
(7) Madras—Bellary	13	16·56	13	16·92	+ 0·36
(8) Bangalore—Bellary	2	37·36	2	37·31	— 0·05
(9) Vizagapatam—Madras	12	9·79	12	9·69	— 0·10
(10) Vizagapatam—Bellary	25	26·39	25	26·61	+ 0·22
(11) Mangalore—Bombay	8	7·37	8	7·55	+ 0·18

The telegraphic circuit errors are as follow :—

				s.
(4) +	(5)	— (3)	=	— 0·01
(5) +	(6)	— (7)	=	+ 0·01
(3) + (6) —	(4)	+ (7)	=	+ 0·02
(7) +	(9)	— (10)	=	— 0·04
(1) +	(8)	— (7)	=	— 0·16
(8) + (4) —	(11)	— (2)	=	+ 0·18

The first four errors are small, and show the work to be of a high order of accuracy ; the two last errors are those of circuits containing the two faulty arcs (1) and (2), which were measured before the defects alluded to in one of the transit instruments had been discovered and rectified; their magnitude is believed to be almost entirely due to this cause.

(79.) It will be noticed that the trigonometrical values are, in almost all cases, greater than the telegraphic. This is partly due to the circumstance that the constants for the Figure of the Earth, which always have been and are still used in the computation of the geodetic latitudes and longitudes of this Survey, are not quite exact; the most modern and exact investigation of the figure—that by Colonel Clarke, C.B., R.E., of the Ordnance Survey—show that our differences of longitude corresponding to the trigonometrical distances between points in Southern India, should be diminished by about $\frac{1}{6500}$th part of their magnitudes. It is also partly due to local deflections of the plumb-line at the stations of observation, and is in accordance with the results of Captain Basevi's pendulum observations, which indicate a probably greater density in the strata of the earth's crust under the beds of oceans than under continents ; for then the plumb-line at stations on the coast would be deflected from the continent towards the ocean, and this would diminish all astronomically determined arcs between stations on the coast and those in the interior, and still more diminish the arcs between stations on opposite coasts of the continent. The excesses of the trigonometrical over the telegraphic arcs which span the Indian Peninsula are 0·63s. = 9″·5 for Madras to Mangalore, and 0·68s. = 10″·2 for Vizagapatam to Bombay, of which probably 3″·0 are due in the former and 5″·9 in the latter instance to the constants used for the figure of the earth, leaving 6″·5 and 4″·3 respectively of excess, which may be due to local attraction of the nature in question.

(80.) On the completion of the operations between Bombay and Mangalore, Captains Campbell and Heaviside proceeded to determine the differences of longitude between Bombay, Aden, and Suez, in order to complete the connexion between England and India, of which the section from Greenwich to Suez had already been executed on the occasion of the Transit of Venus in 1874, under instructions from Sir G. B. Airy, K.C.B., Astronomer Royal.

(81.) It now became necessary to modify very materially the procedure which had been adopted for the previous operations, in order to meet the transition, from land-lines of telegraph and their several recorders, to submarine cables and the syphon recorders by Sir William Thomson, which are exclusively used in the offices at the extremities of the cables at Bombay, Aden, and Suez. In his narrative report, from which copious extracts are given in the Appendix, Captain Campbell has given an excellent description of the manner in which this transition was effected, pointing out the various expedients which suggested themselves from time to time, until at last a method of operation was devised which was found to work very satisfactorily as regards the specific object in view, and also to occasion the minimum amount of interference with the regular work of the telegraph offices. The chief merit claimed for the method devised by Captain Campbell for comparing clocks through a cable is that it may be called automatic, inasmuch as no personal equation of observing or repeating signals can enter. It is believed that this is the first instance of such perfection of method having been attained, as it was not possible in observations taken before the introduction of the syphon recorder. Great credit is due to Captain Campbell for the admirable manner in which he surmounted the various difficulties presented to him at almost every turning; and to Captain Heaviside for his valuable co-operation.

(82.) The Government has also much reason to be indebted to the Eastern Telegraph Company for granting the gratuitous use of their cables, not only during the actual work of signalling, but during the preliminary tentative measures; these involved an amount of intercommunication by cable which would have added very seriously to the cost of the operations, had it been charged for at the usual rates.

(83.) The values of differential longitude which were obtained are—

	h.	m.	s.
Bombay — Aden =	1	51	19·98
Aden — Suez =	0	49	42·66

The value of Madras—Bombay which has been obtained by Captain Campbell, from a combination of the arcs already capitulated, is 0h. 29m. 43·54s. The longitude of the station at Suez relatively to the Greenwich Observatory is 2h. 10m. 13·21s. as determined under the direction of Sir G. B. Airy, Astronomer Royal. Thus the longitudes now determined for India are—

	h.	m.	s.	
The Station at Aden =	2	59	55·89	East of Greenwich.
The Observatory at Bombay =	4	51	15·88	
The Observatory at Madras =	5	20	59·42	

(84.) The longitudes of all places in India are usually [illegible]red to Greenwich through the Madras Observatory, the position of which [illegible] been determined at various times by astronomical observations. The latest determination of that nature is 5h. 20m. 57·3s. = 80° 14′ 19″·5 east of Greenwich, which has for many years been the accepted value, and is given in the current Nautical Almanacs; this value is thus shown to be 2·12 seconds of time, or 31·8 seconds of arc, in defect of what may now be considered to be most probably the true value.

No. XIII.—GEOGRAPHICAL.

HIMALAYAN EXPLORATIONS.

(85.) During the year 1876, the Mullah, one of our explorers, made a survey up the course of the Indus from the point where it enters the plains above Attok, to the point where it is joined by the river of Gilghit. All other portions of the course of the Indus—from the table-lands of Thibet, where it takes its rise, down to its junction with the ocean—have long since been surveyed; but up to the present time this portion has remained unexplored, and has been shown on our maps by a dotted line, the usual symbol for geographical vagueness and uncertainty. Here the great river traverses a distance of some 220 miles, descending from a height of about 5,000 feet to that of 1,200 feet above the level of the sea. Its way winds tortuously through great mountain ranges, whose peaks are rarely less than 15,000 feet in height and culminate in the Nanga Parbat, the well-known mountain whose height, 26,620 feet, is only exceeded by a very few of the great peaks of the Himalayas. The river in many places is hemmed in so closely by these great ranges that its valley is but a deep-cut, narrow gorge, and, as a rule, there is more of open space and culturable land in the lateral valleys, nestling between the spurs of the surrounding ranges, than in the principal valley itself.

(86.) The positions and heights of all the most commanding peaks in this region had been long fixed by Captain Carter's observations at trigonometrical stations on the British Frontier line; but no European has ever yet penetrated into it.* Very difficult of access from all quarters, it is inhabited by a number of hill tribes, each independent and suspicious of the other, who are in a great measure separated and protected from each other by natural barriers and fastnesses. As a whole, the region has never been brought into subjection by any of the surrounding powers. Each community elects its own ruler, and has little intercourse with its neighbours; and with the outer world it only communicates through the medium of a few individuals who have the privilege of travelling over the country as traders. The Mullah possesses this privilege,

* Several itineraries which were obtained from native information are published in Dr. Leitner's Dardistan, and they have been combined together, with considerable ingenuity and very tolerable success, by Mr. Ravenstein, in a map published in the Geographical Magazine for August 1875.

and thus in the double capacity of trader and explorer, he traversed along the Indus, and through some of the lateral valleys, leaving the others for exploration hereafter.

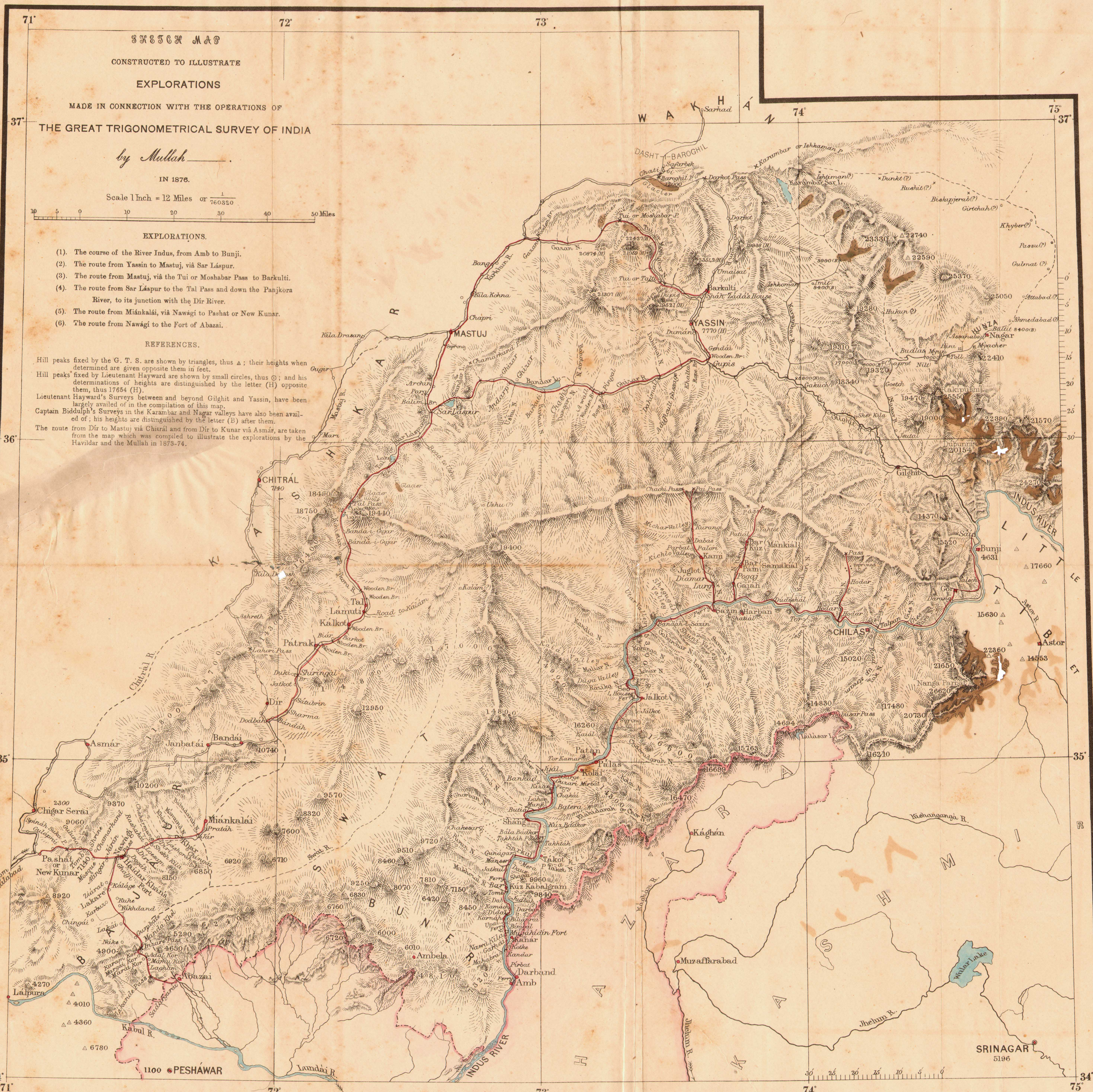
(87.) This work done, he proceeded, in accordance with his instructions, to Yassin, marching through the Gilghit Valley, but not surveying it, because the labours of the lamented Hayward, who was murdered at Yassin, already furnished us with a good map of that region. From Yassin he surveyed the southern route to Mastuj through the Ghizar and Sar Laspur Valleys; this has furnished an important rectification of a route which had hitherto been laid down from conjecture only, and very erroneously; for the road, instead of proceeding in a tolerably straight direction from Yassin to Mastuj, as was supposed, turns suddenly from south-west to north-north-east at Sar Laspur, which is situated at some distance to the south of the direct line, in a valley lying parallel to the valley of Chitral. At Mastuj the Mullah struck on to his survey of the route from Jelalabad, *viâ* Dir and Chitral, to Sarhadd-i-Wakhan, in 1873, and then proceeded along that route towards the Baroghil Pass, as far as the junction of the Gazan with the Yarkhun river, and then along the northern road from Mastuj to Yassin. This road turns up the Gazan Valley, crosses the Tui or Moshabar Pass—which is conjectured to be probably not less than 16,000 feet in height—and, after traversing a deep crevassed glacier for a distance of about eight miles, reaches the point where the Tui river issues in great volume from the glacier; the road then follows the course of the river down to its junction with the Warchagam river, a few miles above Yassin.

(88.) Returning to Sar Laspur, the Mullah next surveyed the route to the south-west, up the valley leading to the Tal Pass. This pass is situated on a plateau of the range which connects the mountains on the western boundary of the valley of the Indus with those on the eastern boundary of the valley of Chitral, and is generally known by the people of the country as the Kohistan. The sources and most of the principal affluents of the Swat and the Panjkora rivers take their rise in this region, all the most commanding peaks of which were fixed by Captain Carter's triangulation; but of the general lie of the valleys relatively to the peaks, nothing at all definite has been known hitherto. The Mullah has done much to elucidate the geography of this region. On crossing the Tal plateau he descended into the Panjkora Valley, and traversed its entire length down to Dodbah, at the junction of the Dir river with the Panjkora, where he again struck on his route survey of 1873.

(89.) It would have been well if he could then have gone down the Panjkora to its junction with the Swat river, but circumstances prevented him from doing so. He therefore travelled along the Havildar's route of 1868 as far as Miankalai, and then surveyed the road to Nawagai and on to Pashat in the valley of Kunar; and finally, returning to Nawagai, he surveyed the road from there down to the British fort of Abazai.

(90.) Thus the explorations of the Mullah have added much to our knowledge of the geography of the interesting regions lying beyond our northern Trans-Indus Frontier. A good deal, however, still remains to be done before our knowledge of these regions is as full and complete as it should be, and every effort will be made to carry out further explorations as soon as possible.

(91.) The accompanying sketch map has been constructed to illustrate the Mullah's operations; it also shows the localities where more information is wanted. In the north-east corner the results of a recent reconnaissance of portions of the Karambar and the Nagar Valleys by Captain Biddulph are given, but somewhat modified from his map of the country.



C. DYSON, PHOTO.

Photozincographed at the Office of the Superintendent, Great Trigonometrical Survey, Dehra Dún, August 1877

C. G. OLLENBACH, ZINCO.

No. XIV.—THE HEAD QUARTERS OFFICES.

CALCULATING, PRINTING, DRAWING, AND PHOTOZINCOGRAPHIC; CORRESPONDENCE; STORES.

(92.) The simultaneous absence of Messrs Hennessey and Cole, and of myself, on furlough during the greater part of the year 1876, rendered it necessary for Major Thuillier, when officiating for me as Superintendent, to assume the direction of the Drawing and Photozincographic Offices, while Major Herschel directed the Calculating and Typographic Offices. This arrangement was continued during the interval from April to October 1876—when Mr. Hennessey, having returned from furlough, was appointed to officiate for me in the place of his junior, Major Thuillier—up to the 13th January 1877, when I returned. Mr. Hennessey then resumed the general charge of the four offices with assistance from Major Herschel, until Mr. Cole's return on the 27th March, when Major Herschel was set free to resume his duties in connection with the reduction of the pendulum observation, by Captains Basevi and Heaviside.

PERSONNEL.

J. B. N. Hennessey, Esq., M.A., Deputy Superintendent, 1st Grade.
Major H. R. Thuillier, R.E., Officiating Deputy Superintendent, 1st Grade.
Major J. Herschel, R.E., Deputy Superintendent, 2nd Grade.
W. H. Cole, Esq., M.A., Assistant Superintendent, 1st Grade.

Computing Branch.

Mr. C. Wood, Surveyor, 3rd Grade.
„ H. W. Peychers, Surveyor, 4th Grade.
Baboo Gunga Purshad, Computer.
„ Cally Mohun Ghose, „
„ Kally Coomar Chatterjee, Computer.
and
Eleven other Computers.

Printing Branch.

Mr. M. J. O'Connor, Printer.
Sixteen Compositors and Apprentices.

Photozincographic Branch.

Mr. C. G. Ollenbach, Zincographer.
„ C. Dyson, Photographer.
Two Apprentice Photographers, one Native Draftsman, two Apprentice Draftsmen, and a Map-keeper.

Drawing Branch.

Mr. G. W. E. Atkinson, Surveyor, 3rd Grade.
Jafir Khan.
Two other Draftsmen, four Assistant Draftsmen, also some Apprentices and Map-colorists.

Correspondence and Stores.

Harry Duhan, Esq., Personal Assistant.
Mr. L. H Clarke, Surveyor, 2nd Grade.
Baboo Raj Krishna Mukerjee.
and
Two other Writers.

(93.) Major Herschel's investigations of the influence of local attractions, and the variations of continental and oceanic gravity, on the swings of the pendulums, had necessarily been laid aside during the entire period—upwards of a year—when he was holding charge of the Computing Office, as his time was then very fully occupied with the duties of that office. The interruption was, however, found to be not without advantage, leading to a better arrangement and closer grasp of the subject, and more clearly defining the limits within which reductions might be profitably undertaken, so that the value of the results may be at all commensurate with the labour of the numerical calculations. It has thus been ascertained that much of the labour which is usually bestowed on reductions of this nature is unnecessary, and that approximate formulæ, the application of which involves far less of calculation, may be employed with sufficient accuracy for the required purposes, seeing that there is very much of uncertainty as to the true values of some of the principal facts which enter into the investigations. In his report on the prosecution of the reductions (Appendix, page 63—a), Major Herschel dwells on the failure of any known conditions of the earth's form or constitution to explain the variations of gravity which are evidenced by the pendulum; but he arrives at the conclusion that, though pendulum results are subject to errors which we have no prospect of eliminating, their number should be increased, both locally and generally over the whole globe.

(94.) Much valuable work has been done during the year in the Computing Office. The final reduction of the North-East Quadrilateral—that section of the Great Triangulation which includes all the principal chains of triangles situated to the north of a line running from Sironj in Central India through Calcutta to the Eastern Frontier, and to the east of the meridian of Sironj—was commenced during the previous year under Major Herschel's supervision, and has been completed this year. The reduction was effected in continuation of, and on the same principles as, those of the North-West and the South-East Quadrilaterals, which have been described in previous reports in sufficient detail to obviate the necessity for any further exposition of the subject in this place. Various other calculations and reductions have been made, the principal of which are given in the extract from Mr. Hennessey's report in the Appendix.

(95.) Considerable progress has been made since my return from Europe with the 2nd volume of the Account of the Operations of this Survey, the greater portion of which is now completed and has been passed through the press. It gives a brief history of the operations, a full description of the procedure which has been followed, and of the instruments which have been employed in the measurements of the angles, and all the mathematical formulæ which are used in the reductions. It also gives full details of the simultaneous reduction of the North-West Quadrilateral; these it has been found very difficult to present in a compact form, divested of the greater portion of the numerical results which were obtained during the successive stages of the calculations, and yet containing every factor which is essentially necessary to enable the results to be readily tested and verified; for the calculations are exceedingly numerous and intricate, and somewhat difficult to follow.

(96.) The Drawing Office has been chiefly employed in the preparation of charts of the triangulation in illustration of the synoptical volumes which are published on the completion of the final reductions, and also in continuing the charts of levels which give the results of all existing lines and systems of levels, by whatever department executed, combined together and reduced to a common datum. Maps have been constructed to illustrate the explorations of the Mullah, and the report on Gilghit by Captain Biddulph. And much good work has been done in the examination of maps and charts sent in by the survey-parties for publication.

(97.) The Printing and Photo-zincographic Offices have been very fully employed, and, in fact, have found much difficulty in grappling with the amount of work which they have had to deal with, and which increases annually. Heavy arrears had been allowed to accumulate towards the end of the previous year, which was in some degree owing to a want of attention on the part of the topographical draftsmen to the style of drawing required for maps which have to be reproduced by photo-zincography: for a map may be very beautifully executed, and yet be unsuited for reproduction by this cheap and expeditious process which is so valuable when speedy publication is wanted; but the arrears were to some extent also due to a want of method in the working of the office. They have now been nearly all cleared off, and a very short interval now elapses between the receipt of a map from one of the survey-parties and its publication after due examination.

(98.) Mr. Hennessey warmly acknowledges the valuable and varied assistance which he has received on all occasions from Mr. W. H. Cole, M.A.; he also reports very favourably of Mr. Wood, Mr. Peychers, Baboo Gunga Pershad, and Baboo Cally Mohun in the Computing Office, and of Mr. Atkinson in the Drawing Office, and satisfactorily of Messrs. O'Connor, Ollenbach, and Dyson.

(99.) Mr. H. Duhan, my Personal Assistant, has rendered much valuable service in the general supervision of the Correspondence Office; and Mr. L. H. Clarke has worked heartily and well in the performance of his varied duties.

J. T. WALKER, *Colonel, R.E.*,
Superintendent, Great Trigonometrical Survey.

CALCUTTA,

31st December 1877.

Abstract of the Out-turn of work executed by the Great Trigonometrical Survey Parties during the Survey year 1876-77.

Description of Details.	Madras Coast Series, 24-inch Theodolite.	Assam Valley Triangulation, 12-inch Theodolites.	Burmah Secondary Triangulation, 12 inch Theodolites.	Eastern Frontier Series, 24-inch Theodolite.	Eastern Sind Series, 24-inch Theodolite.	Kattywar Topographical Survey.	Guzerat Topographical Survey.	Kumaon and Garhwal Topographical Survey.	Spirit-levelling Operations.	Total.
Number of principal Stations newly fixed ...	15	...	...	12	26	...	...	...	...	53
Number of principal Triangles completed ...	18	...	...	17	32	...	—	...	...	67
Area of principal Triangulation, square miles ...	532	...	...	2,032	2,455	...	...	...	...	5,019
Lengths of principal Series, in miles .	52	...	...	92	125	...	...	...	...	269
Average Triangular error, in seconds	0·81	—	...	0·46	0·36	...	...	...	...	...
Average probable error of Angles, in seconds ± ...	0·17	...	...	0·42	0·14	...	...	...	...	...
Astronomical Azimuths of verification observed ...	1	...	...	...	1	...	...	...	...	2
Number of principal Stations selected in advance ...	5	...	...	13	21	...	...	...	...	39
Lengths of principal Approximate Series, in advance ...	20	...	...	56	98	...	...	...	...	174
Number of Pillars and Platforms constructed for principal Stations ...	10	...	...	14	30	...	...	...	...	54
Number of Scaffolds erected for principal Stations ...	13	...	...	...	...	...	...	...	...	13
Number of principal Stations placed under official protection ...	13	...	22	15	24	...	...	...	...	74
Number of principal Stations protected and closed ...	7	...	44	20	24	...	...	...	...	95
Number of Secondary Triangles of which all three angles have been observed ...	...	22	32	9	3	160	112	35	...	373
Number of Secondary Triangles of which only two angles have been observed ...	...	256	104	46	55	1,554	315	186	...	2,516
Number of Secondary Stations the positions of which have been fixed	...	21	...	...	...	83	89	39	...	232
Number of Points fixed by intersection but not visited ...	2	112	60	20	3	891	156	96	...	1,340
Number of Revenue Survey Stations and Boundary junction pillars fixed by Triangulation ...	...	...	...	...	28	...	—	...	...	28
Number of Stations and Points the heights of which have been determined ...	...	116	90	25	32	482	78	83	...	906
Length of Secondary Series, in miles .	...	63	176	...	8	...	...	70	...	317
Area of Secondary Triangulation, in square miles ...	...	477	2,522	...	140	2,062	2,480	870	...	8,551
Area embraced by Triangulation to hill-peaks, in square miles ...	...	6,100	2,100	2,400	...	...	...	13,000	...	23,600
Number of Pillars, Platforms, or posts for Secondary Stations, constructed or repaired ...	—	33	14	6	5	270	667	...	...	995
Length of Boundary lines and Check-lines traversed, in linear miles ...	...	...	...	...	...	752	1,965	...	...	2,717
Area Topographically surveyed on scale ½ inch = 1 mile, square miles	...	...	...	...	...	...	...	959	...	959
Area topographically surveyed on scale 1 inch = 1 mile, square miles	...	...	...	...	...	...	..	640	...	640
Area topographically surveyed on scale 2 inches=1 mile, square miles	...	...	...	...	...	1,716	1,988	...	...	3,704
Number of miles of rays cleared ...	272	250	28	2	20	...	...	...	...	572
" " pathways made	...	34	...	30	...	...	...	...	...	64
" hill-tops cleared of forest and jungle ...	...	3	16	24	...	...	...	...	...	43
Number of miles levelled over ...	...	...	...	...	...	...	...	...	375	375
" permanent Bench marks fixed ...	...	...	..	...	...	—	—	—	306	306
Astronomical Azimuths of verification computed ...	1	...	...	...	1	...	...	...	...	2
Number of principal Stations the elements of which have been computed	15	...	...	14	24	...	...	...	...	53
Preliminary Charts of Triangulation	1	1	2	1	1	...	...	...	...	6
Number of Secondary Stations the elements of which have been computed	...	135	92	27	33	969	...	66	...	1,322
Number of Points fixed by traverse and their elements computed ...	37	...	...	...	1	2,131	6,041	...	...	8,210
Barometrical determinations of heights	...	...	...	...	...	...	...	192	...	192
Number of Topographical Maps completed ...	...	...	...	...	...	14	32	5	...	51

APPENDIX.

EXTRACTS FROM THE NARRATIVE REPORTS

OF

THE EXECUTIVE OFFICERS IN CHARGE

OF

THE SURVEY PARTIES AND OPERATIONS.

I.—Extract from the Narrative Report, dated 15th August 1877, of Captain T. T. Carter, R. E., late in charge Madras Party.

On my arrival at Bombay, on return from furlough to Europe, I proceeded to Bangalore, and on the 20th of November took over charge of the Madras Party from Captain W. M. Campbell, Royal Engineers, who had held charge of the same during the absence on leave to Europe of Major (now Lieutenant-Colonel) Branfill.

The party, consisting of the officers and establishment as per margin, were despatched as soon as all arrangements could be made, and arrived at Tanjore on the 1st December.

Captain Carter, R. E., Deputy Superintendent, 3rd grade.	Mr. A. H. Bryson, Asst. Surveyor, 3rd grade.
Mr. G. Belcham, Surveyor, 4th grade.	1 Hospital Assistant.
Mr. C. D. Potter, Asst. Surveyor, 1st grade.	55 Klassies.
	14 Burkundazes.
24 Carriers.	

State of the work at close of past season.

During the field season 1875-76, the Madras Coast Series had been advanced by two hexagons observed, and by the selection of sites and construction of the masonry pillars for the stations of two more hexagons.

Mánikkamkottei. Okkúr.

The angles at the two stations of continuations had also been observed during the past season; consequently, the scaffoldings which form the platforms both for the observer and signallers had been constructed for three stations of the new polygon. These, however, required repair and looking to before they could be used; the platforms for the remaining three stations of the figure had to be constructed and the rays between stations finally opened out, as they had only been partially cleared the previous season; this was the first work to be done as regarded the Okkúr polygon; with reference to the Mepankád or second hexagon selected in advance, there was still some uncertainty as to whether the two last stations would be visible from the central station.

Karká Kurichi.

Distribution of officers on first taking the field.

The following distribution of officers was made on first taking the field: Mr. Belcham was directed to proceed to the central station of the hexagon last chosen, and at once satisfy himself that mutual visibility could be obtained between that station and the two stations in advance referred to above, and, if not, to select other sites; he was then to superintend the buildings of the scaffoldings at two stations and open out the ray between them. Mr. Belcham set to work with his usual zeal, and luckily it was found that there was no difficulty in obtaining visibility between these stations; and by the end of the month he had completed this portion of the work allotted to him. Mr. Potter was directed to build the scaffolding at one station and to clear the rays from it; subsequently, to repair the scaffolding at another (erected the previous season), and to raise the pillar there from 2 to 8 feet: as it was found that the height of eye was not sufficient; he began his work on the 10th of December.

Mr. Bryson was deputed to carry out similar work which he commenced on the 16th of December. I proceeded myself to Shemblavayal P. S., the first station from which observations had to be taken, and arrived there on the 18th of December, having visited Messrs. Belcham and Potter on my way.

Prevailing scarcity of grain and water.

As was natural to expect, having taken the field with a party quite new to me, there was some delay at first starting; moreover, owing to the famine prevailing in Southern India, there was a difficulty in procuring provisions; rice was selling at 5 seers for a rupee, the people had migrated in large numbers to Ceylon, and those that were left seemed little inclined to part with their grain; moreover, there was a threatening of a water famine, the tanks at this time (middle of December) being nearly dried up. However, by suitable arrangements, the difficulty as to feeding the camp was got over, and all fear of a water famine was over, when, on the 23rd of December, heavy rain fell and continued to the 26th.

Observations were begun at Shemblavayal P. S. on the 27th of December, and the station was completed on the 30th.

Commencement and final observations by Captain Carter and Mr. Belcham.

From Major Branfill's report of the previous season's work I was aware that Mr. Belcham had taken a considerable part in the "principal observations" of that year. I was also desirous of obtaining from Mr. Belcham a knowledge of Major Branfill's mode of procedure with reference to the observatory work, as well as an insight into the characters of the different men of the establishment. I therefore decided to call him in to assist in taking observations; the result was very satisfactory, and it enabled me to complete the observations at seven stations by the end of January. The plan I adopted was to observe on one zero while Mr. Belcham recorded; the next zero we changed places, Mr. Belcham observing while I recorded. There was no native recorder attached to the party, and, had I not adopted this plan, I should have been obliged to recall Mr. Bryson to record, and as he has had no experience in observing with a 24" theodolite, his services would only have been of use as a recorder, and the observations at these seven stations would probably have taken double the time. Mr. Bryson was as able as Mr. Belcham to construct scaffoldings, and it was also desirable that he should have some practice in selecting and building stations. I think credit is due to Mr. Belcham that he is able, when necessary, to take a share in the principal observations.

Final observations continued and completed by Captain Carter.

On the completion of observations at Mepankád, Mr. Belcham was deputed to continue the approximate work. Mr. Bryson was recalled as observatory recorder, and continued as such during the remainder of the field season; he was also employed in fixing by "theodolite and chain traverse" any buildings of a permanent nature in the vicinity of the principal stations: observations were completed at eight more stations by the end of the field season; at the station of Pátharankortei, an azimuth of verification was observed, the two stars selected being α Ursæ Minoris (polar star) and B Ursæ Minoris for eastern and western elongation respectively.

Mr. Belcham.

Mr. Belcham, on being relieved from his duties in the observatory on the 1st February, proceeded to take up the approximate work and was employed on this duty till the close of the field season. Although he only completed the selection and building of three stations and the clearing of the rays to and from the same between the 5th of February and 14th of April, this slow progress appears to have been entirely due to the unfavourable nature of the ground and the heavy cutting that had to be got through. The aspect of the country had altered very considerably, consisting now of paddy fields hedged round with babul trees very difficult to get through, and the ground much cut up with water-courses.

Mr. Potter.

Mr. Potter having completed the repairs at stations, as directed, proceeded to Mepankád P. S., and in conjunction with Mr. Bryson (who was directed to work under Mr. Potter's orders), had completed the buildings of the scaffoldings of, and the clearing of the rays between, the stations of the Mepankád (or second) polygon by the 11th of January. Mr. Potter then proceeded to take in hand the next figure, assisted by Mr. Bryson. Mr. Bryson was recalled to act as observatory recorder on the 3rd of February, and the approximate work was continued by Messrs Belcham and Potter. Mr. Potter's progress had been very good; in a little over a month he had selected and built three stations with their scaffoldings and cleared the rays between the same, but he now experienced the same difficulties on the eastern flank as Mr. Belcham, who was working on the western flank, and his progress was consequently slower than at the commencement of the season; he closed work on the same date as Mr. Belcham, *viz.*, the 14th of April.

Paruttikóttei.

Mr. Bryson.

Mr. Bryson's work has been already mentioned.

Messrs. Belcham, Potter and Bryson worked cheerfully and well, and I have every reason to be satisfied.

Secondary triangulation.

Little or no secondary triangulation could be done, the country lying low, without much difference in level, and in most places thickly covered with mango and palmyra groves; points observed to form one station were seldom seen from another. A considerable number of masonry buildings (chiefly temples) were fixed by a "theodolite and chain traverse" to serve as points from which the position of the principal stations could be found in case the pillar and mark-stones above ground should at any time have been removed; their position being known will also be useful in any future survey of the country, as they are buildings likely to endure for a considerable time.

Connection with Colonel Lambton's work executed in the beginning of the present century.

As our triangulation was approaching that of Colonel Lambton's executed in the year 1800, I endeavoured to find out if any of his marks could be found on the different pagodas shewn on the chart of his triangulation, which were evidently used by him as stations of observation. The pagodas of Munargudi, Alangudi, Combaconum and Tanjore were examined for this purpose, as well as the *goparam* or "gateway" leading into the enclosure in which the pagoda stands; the general description given of these stations is "on the pagoda," though in all probability the instrument was placed on some part of the *goparam*, which is usually a much loftier structure than the pagoda or temple. I regret to say that in no instance did I find a mark. An endeavour was also made to find the terminal marks of the Vellum Base Line in case it was thought desirable to connect it with our triangulation, but without success, the only station of Colonel Lambton's triangulation, the exact position of which can be identified as far as the work has gone at present, is that at Budalur, the mark-stone of which is protected and kept in repair by the civil authorities. The question of identification of these stations of Colonel Lambton's triangulation I brought to the notice of Colonel Branfill on his re-assuming charge of the party.

Protection of stations.

The whole of the stations at which final observations were completed were protected and made over to the civil authorities as directed in Departmental orders No. 1 of 1866. Generally, the protecting mound of earth was turfed over; the station was further protected by having a cactus hedge planted round it, which also served to shew the limits of the ground taken up by Government. In several cases this small plot of ground was bought, and I was in communication with reference to the purchase of the same in every case, and a transfer of the land from the owner's name to that of Government on the land registers; there would always then be a permanent record for reference in future years as to the position of the station.

Instrument.

The 24-inch theodolite No. 2, by Troughton and Simms, worked well, though there was a tendency for the readings to diminish on the return to the same point, and this whether the telescope was moved from right to left, or left to right; it was particularly perceptible when observing the azimuth at Pallicorankotei, where the referring mark was being constantly intersected. I attribute it to the expansion and contraction of the 17½ feet stand which in this party has taken the place of masonry pillars. In the beginning of the season the stand was protected from the prevailing wind from the north-east; the extremes of temperature were not so great, and it was not till March that I observed this peculiarity. By protecting the stand on all four sides, I found that, though there was still a tendency for the readings to diminish, the decrements were much less. I must mention a curious feature in the case, *viz.*, that though there was this tendency for the readings to lessen each time that the telescope was pointed at the same object, the levels attached to the body of the instrument (one of them a particularly sensitive one) remained very constant. The triangular errors are large, and this I can only account for by the rays being grazing, and often passing over tanks and rice swamps; the signals were steady, and I had only on one occasion to stop work on this account, and this unsteadiness was due to the lamp-man neglecting to isolate his lamp from the part of the platform on which he sat: of course, there is a tendency for such high scaffoldings to oscillate, the guy ropes want constant tightening, and the plumbing looking to; the scaffoldings (from which the signal was shewn) averaged 45 feet in height, on one occasion one had to be raised to 60 feet to overcome a rise in the ground, and this was done without much difficulty. The deflection at this height was very slight, even in a high wind, verifying the opinion of Captain Campbell expressed in paragraph 3 in appendix to Major Branfill's report of last year. The scaffoldings were built of the palmyra palm-tree, which was generally procurable near the station; it is, however, heavy and cumbersome to move; the areca palm-tree, which I believe was used on the southern portion of the series as well as on the Ceylon connection series, was not procurable in the district, and the officers employed on the construction of these scaffoldings had to make the best of what timber could be got on the spot.

Health of the party.

The health of the party was very good; two men were attacked by cholera on first taking the field, one of whom died; and this was the only casualty.

LIEUTENANT-COLONEL BRANFILL'S LIST OF PLACE-NAMES.

Proper names of Stations and Places given on the preliminary charts of the Madras Party, Great Trigonometrical Survey of India, for the seasons 1875-76 and 1876-77, along the coast of Madura and Tanjore, from Rámesvaram to Point "Calimere" (Kallimédu).

"Adrampatam" ... See Indian Atlas Sheet No. 80	... short for Adi-víra-Ráma-pattanam, the (seaport) town of Adi-víra Ráma, one of the Pándyan princes of Madura, its founder.
Ámanakkamunei ...	... "*Castor-oil plant headland*"—from *ámanakkam*, the castor-oil plant which grew there; and *munei*, a point or headland.
Arantángi	... "*Charity station*"—from *aram*, charity; and *tángi*, a support.
Ávideiyár Kóvil ...	... name of a large temple (*kóvil*) in the south of Tanjore, from Ávudayár one of the names of the lingam, the sacred phallic symbol of Siva; *ávudayár* means "*ox-owner*" (*ávu* =, ox), and Siva is commonly represented as riding on a bull.
"Calimere" ... ... See Indian Atlas Sheet No. 80.	... properly Kallimédu, "*Euphorbia mound*," the north-east headland of Palk's Straits (the Argaric gulf), between India and Ceylon. This point is also called *kódi* = the point, the same as the other or southernmost extremity of the gulf at the south extremity of Rámésvaram.
Chevidan Kóttei ...	... "*Deaf one's fort*" (*chevi* = ear)—*chevidan*, a deaf man; and *kóttei* a fort or fortified village.
Dévipattanam ...	... "*Devi's-town.*" *Dévi* = "*the goddess*" is a name of Siva's consort, Párvati.
Elnúthimangalam ...	... from *élu*, seven; *núru*, a hundred; and *mangalam*, delight, joy, matrimony.
Gandhamána Parvatam ...	... the little eminence about a mile north of Rámésvaram temple, so named after one of the leaders of Rámá's army when attacking Lanka (Ceylon), as told in the Rámáyana.
Gópuram	... the lofty tower or spire over the entrance gateway of a temple or town in Southern India—from *kóppu*, a pointed roof, spire, or dome, which, perhaps, is from the same root as cupola, coping, cap, &c.: compare Hind. *kubba*, a dome.
Kád *or* Kadu ...	... a wilderness, jungle; an untilled or unirrigated field, fit for dry crops only; the root *ká* means a grove, wood, or garden; also a beam or boom; cf. S. *káth*, wood timber.
Kakkrá Kóttei ...	... "*Kaka-Ráman's fort.*"

Kallá Kóttei	"*Stoneless fort*"—from *kal*, a stone; *illei*, the negative = without; and *kóttei*, a fort.
Kalúrunikád	"*Stone-tank-field*"—from *kal*, a stone; *úruni*, a common village tank, a horse-pond; and *kàdu*, a jungle, a dry or untilled field.
Kánád	? "*Wilderness*"—from *kán*, a jungle, forest; and *nádu*, a country, district.
Karká Kurichchi	"*Karkan's settlement*"—from the proper name of a man, and *kurichchi*, a small village or hamlet, strictly of mountaineers or foresters.
Kodikulam	properly *kódiyar kulam*, and said to be from *kódiyar*, robbers, because this village had been repeatedly attacked and spoiled.
Kollei	a field, enclosure; a dry unirrigated field, high ground, a grove; met with repeatedly in South Tanjore, but not noticed further south near the coast.
Kollukkádu	"*Grain-field*"—from *kollu*, the horse-gram (vulg. *kulti*) of Southern India.
Kulamangalam	from *kulam*, a tank or reservoir; and *mangalam*, prosperity.
Manigandi	"*Bell-ringer's(village)*"—from Sanskrit *mani*, a bell; and(. . . . .), a word meaning to strike. This village is said to have been given to an attendant of the Tiruvádáni temple, whose duty it was to perform the bell-ringing there; a former name of the place was *Márgandayarpuram*.
Mánikkamkóttei	"*Manikkam's fort;*" *mánikkam*, a ruby, from (Sanskrit) *mani*, a gem.
Mánúr	Derivation uncertain.
Maruthangón Viduthi	? "*Hermit's lodge*"—from *maru*, the marriage-feast, a ceremony; *thangón*, one who does not remain, an absentee, truant; and *viduthi*, a lodging-place, a separate apartment; solitariness, separation.
Masána Karei	"*Cemetery shore.*" The Hindu pilgrims who die at Rámésvaram are commonly buried at this spot, and their bones lie scattered on the surface, or but half-buried in the sandy waste near the sea-shore. Hindu burning or burying places are usually on the bank (*karei*) of a river or tank.
Mayivayal	"*Peacock's field*"—from *mayil*, a peacock (perhaps from one of the noises or calls he commonly makes. In Canarese the corresponding name is *navil* or *naul*, but the Tamil *mayir*, and the Canarese *nuviru*, both mean hair, a tuft of hair, and may well refer to the peacock's tuft or crest.)
Mélapattu	"*Upper* (=*west*) *ville.*" *Méle* is very frequently used in contradistinction to *kíle* which first means under, below, and hence, eastern, as the country of Southern India falls as you go eastward. *Pattu* is a common suffix to place-names in South Tanjore, and seems allied to *patti* a cattle-fold, a hamlet, also to *pattanam* (*patam*) *pat*, and possibly to *pettei* and *pádi*, &c.
Mépankád	a vulgar form of Mérpaneikádu—"*West palm jungle*"; *mér* for *mélé* upper, *i.e.* western; and *panei*, the palmyra.
Mukutu kollei	"*Corner field*"—from *mukku*, a nook or corner; and *kollei*, a field or enclosure. Another place near this, Kona kollei, has the same signification.
Nádankádu	Nádán is a title amongst the Shánárs (toddy-drawers), and *nádan* an epithet applied to the Chola kings.
Nariyankádu	? "*Fox-hurst*" "*Dwarfs-wood*"; *nari* means a fox; *nariyan*, a man as cunning as a fox; it also means a dwarf.
Nayenár Kóvil	"*Nayenár's temple*"; *náyanár*=lord, master, a title applied to Siva from the same Sanskrit root as *nàyak*, a leader (*naik*), and *Náyar*, the Nairs, or honoured Sudras of Malabar.
Neduvá Kóttei	"*Long fort*"—from *nedu*, long (not to be confounded with *nadu*, middle) and *kóttei*, a fort.
Neduvan Tivu	"*Long island*"—from *nedu*, long, and *tívu*, the Tamil form of Sanskrit *dvípa*, an island. The Dutch Government in Ceylon had a small horse-breeding establishment here, and called the island Delft.
Okkúr	Derivation uncertain, but stated to mean the village of one family, or the "*united village.*"
Omathei-nádu	Omathei is the Tamil name of the *datura*, a stupefying plant; and, *nádu*, a district, country.
Pallathivayal	"*Palla-woman's-field.*" Pallans are a tribe of low outcastes in Southern India; and *vayal*, a rice-field. This word *vayal*, a field, rice-field, an open plain or flat, is one of the commonest affixes to village names in Southern India. In Canarese it is *bayalu* or *bailu*, but on most of the older maps and charts the name is disguised under many erroneous forms, such as *bile*, *byl*, *vail*, *voil*, *voyal*, &c.
Pasala Kollei	"*Green-field*"—from *pasumei* and *pachchei*, green; and *kollei*, a field, &c.
Pátharan Kóttei	"*Pátharan's fort.*"
Pattu Kóttei	*Pattu* is a common affix, and an occasional prefix, to the names of small towns and villages in S. E. Tanjore; it may mean a silk (flag), and perhaps a grant, or a crown, or it may be from the same root as *pattanam*, a town; *patti*, a (cattle) fold; or *pettei*, a town or suburb with shops.

Periya, peru, per ...	... Great-Telegu *pedda*; compare Hind.; *bara* or *bada* great (in Canarese *dodda*).
Peruntámarei	... "*Great lotus*;" from *peru*, great, and *tamarei* the lotus.
Pinneiyúr	... ? "*Rear town*;" *pinnei* means after, farther; compare *Porakudi*.
Porakudi	... ? "*Back house*," from *pirage*, behind; perhaps because this place is behind, or at the back of, the seaport town of Devipattanam.
Pórakudi	... "*Battle dwelling*;" from *por*, fight, battle, and *kudi*, a habitation, dwelling.
Pudukóttei ... ... "*Poodoocottah*" of Indian Atlas No. 80.	... or Puthu kóttei, "*new fort*;" from *puthiya*, new, and *kottei*, a fort. This is the chief town of the Tondimán Rajah's country, south of Trichinopoly.
Puthu viduthi ...	... "*New lodge*;" from *puthiya*, new, and *viduthi*, a temporary abode.
Púvatúr	... "*Flower village*;" from *pu*, a flower, and *ur*, a village.
Retta vayal	... perhaps for Irattavayal.="*Double field*:" *rendu* is the vulgar form of *irandu*, two, and *rettayana* of *irattiyana*, double.
Rudra Chintámani ...	... *Rudra*, a name of Shiva, one of the demons or demi-gods, and *Chintamani*, a mythical gem, the philosopher's stone, one of the gems of Swarga (heaven), yielding its owner all his desire.
Sengáttán kudi ...	... a dwelling sacred to Shiva, who prefers the colour red, and sleeps on a bed of red lotus. *Senkadu* or *Chengád* (="*red-wold*," "*bloody field*") is the simple form of the word, from *sem*, red, beautiful, *kadu*, wilderness, and *kudi*, a dwelling.
Shembalavayal ...	... ? "*Red-rice-field*," for *sen-nel-vayal*, or more probably for *sempalavayal* ="*bloody field*," "*field of battle*."
Sigankádu	... from *sigam*, an acid fruit-tree; the *tamarattei*.
Sirukambur	... or Sirukambeiyur said to be from *siru*, little, *vambi*, quarrel, and *úr*, village, *Petty-quarrel-town*, or "*Squabble-ham*."
Tanjore or Tanjá-ur ...	... commonly called by the natives Tanjá-úr, Tanjei, and Tanjam= "*Tanjan's town*"; but the proper name in full is said to be Tanjei-mán-nagaram=*Prince Tanjam's city*. *Tanjam* means a refuge, and *mán* (for *mannan*), a prince, hero, a man in his prime, as in Tondaman, Chéramán.
Thenamanádi	... "*South aspect*" or south division; from *ten*, south, southern.
Thondarápattu ...	... ? "*Servant's hamlet*" or "*Devotee's abode*;" from *thondan*, a servant, adherent: see Pattukottei.
Tiruchitambaram ...	... a local name of one of the "*Chellambram*" (=*Chitambaram*) temples. *Tiru* means holy, sacred, illustrious, and is the Tamil form of the Sanskrit *Sri*.
Tirunálur	... "*Holiday village*;" from *tiru*, holy, *nal*, day, and *ur*, a village, *tirunál*, holiday.
Tiruppu vayal ...	... "*Holy-flower-field*;" from *tiru*, holy, *pu*, a flower, and *vayal*, a rice-field.
Tiruvádáni	... name of a place with a considerable temple dedicated to a deity represented as having the face of a sheep, *ádu*, and the body of an elephant, *ánei*; the initial *tiru* means holy, and is the Tamil form of the Sanskrit *Shri* or *Srí*.
Tondamán	... The title of the Chief or Rája of Pudukottei, a little to the south of Trichinopoly. *Tondan* means a servant, adherent, devotee; and *mán* (for *mannan*) a prince, a man in his prime: compare *Chéraman*=Prince of Chéra. Tondei or Tondamandalam is the name of the region or country of which Kánchipuram (Conjeveram) was the chief town.
Uranakudi	... or Uranakudi, said to be derived from *úr*, a town, *annam*, rice, and *kudi*, a dwelling.
Urimunei	... a headland in Neduvan Tivu (also called Delft by the Dutch in Ceylon), from the little spiral shells (*uri*) which abound there.
Vánakkankádu ...	... "*Baniyan's field*." *Vánigan*, a trader=*chetti* or *séth*.
Vandal	... Dregs, silt, mud from tank-beds; this word appears in the names of villages in Madura, perhaps from their having been built on a ridge of gravel drift, on a spoil-bank, or on the grit heaps left in the waterway of a flooded river or breached tank.
Vayal	... a rice-field, an open field or plain; a very common affix to village names on the S.-E. and E. coasts of Southern India: see Pallathivayal.
Vellálankádu	... "*Vellálan's jungle or field*." *Vellálans* are an agricultural caste or tribe of Tamils. *Vellánmei* means cultivation, or strictly *flood-ruling*, *i.e.*, irrigation.
Véndán viduthi ...	... ? "*Hermit's lodge*." *Véndán*, means not wanted, and is applied colloquially to a sulky, disagreeable man; a recluse.
Venniyur	... a hamlet, named after the local goddess *Venniyamman*. Another name for this place is *Muppur* or *Muppeiyur*, a corrupt contraction from *Mummudisolapuram*. There is a local tradition that the three princes (*munu* three, *mudi* crowns), Pándiyan, Solan, and Chéran, once met together here.
Vettanúr	... "*Hunter's village*;" from *vedan* a hunter or forester, the name by which the aboriginal wild tribes of Southern India are known, the *Veddahs* of Ceylon.
Vettivayal	... "*Worthless field*;" from *vetti* vainness, uselessness.

Viduthi ... ... a lodging-place, temporary abode; this affix to village names seems to be specially common in South Tanjore and East Pudukottei.

Virappavayal ... ... "*Virappa's (rice) field.*" *Virappa* is a common proper name of men in Southern India from *Viran*, a hero, warrior (compare Latin, *vir*), and *appan* a father (compare Hebrew *ab*, Chaldee *abbá*, and Hind. *áp*).

Vitrá vayal ... ... "*Fertile or fruitful field,*" from *vittu*, seed.

Provincial place-names common in Rámnád and South Madura, not found at all, or very scarce in South-East Tanjore (see Indian Atlas Sheet No. 80 :—

(*a*) éndal ... ... eminence; commonly applied to a hamlet with a small tank in Madura.
(*a*) kammáy ... ... or kammay, an irrigation tank, or reservoir of water.
(*a*) karei ... ... a bank, shore, border.
karisal ... ... blackness, the black (cotton) soil; *karshá kulam*=black (soil) tank.
Maravan ... ... (plural Maravar), name of the chief tribe or caste inhabiting the Rámnád and Shivagangei zemindáries.
(*a*) ódei ... ... a water-course, stream.
pottal ... ... barren, brackish soil, an arid tract.
taravei ... ... a salt marsh or swamp.
(*a*) úruni ... ... a common village tank.

Provincial place-names newly met with in South Tanjore :—

kollei ... ... a field, enclosure; a dry, unirrigated field; high ground. More common farther north.
pattu ... ... derivation unascertained as yet.
viduthi ... ... a lodging-place, temporary abode. This word seems peculiar to the Pattukottei taluk, east of Pudukottei.

The common South Indian place-names most frequently met with in the extreme South Tanjore Country under notice are :—

(*c*) kádu ... ... a jungle, wilderness.
(*c*) kóttei ... ... a fort, fortified village.
kudi ... ... a dwelling, habitation.
(*c*) kurichchi ... ... a small village, properly a settlement of hillmen or foresters.
(*d*) Pattanam ... ... a town, or seaport town. In 50 miles of this coast there are 24 places of this name (see Indian Atlas Sheet No. 80).
taru ... ... a street; a common term for the little hamlets in each parish or village.
úr ... ... a town or village; probably the commonest affix over all Southern India.
(*d*) vayal ... ... a rice-field, a patch of rice-cultivation, very common also especially in the low country.

The following place-names, so common in other parts of Southern India, are here "conspicuous by their absence" :—

Bádi or pádi, chéri, palli, patti and puram, the commonest Tamil hamlet or village names.

(*a*) áru, éri, gunta, kulam, kuttei, and samundram, affixes meaning river, lake, tank, or pond, &c.

(*b*) *médu, parambu, párei, and kal, a mound, hillock, or rock, as well as giri, malei,* and *kunru,* a mountain or hill; also nattam, páleiyam, puram, and valasei, common village names with various meanings.

General Note to accompany list of place-names for 1876-77.

The portion of country traversed by the Madras Party of the Great Trigonometrical Survey of India during the past season, skirts the coast of South Tanjore for some 50 miles along the North-western shore of Palks Straits (the Sinus Argaricus of Ptolemy), extending only 20 miles inland, and lies between the deltas of the Veigei (Véghavati) and the Cauvery (Kávéri) rivers. It is crossed by a few unimportant streams which drain the Tondiman or Pudukóttei Rajah's territory) under the Trichinopoly District), but is devoid of any large streams or lakes.

Going north-east-wards from Rámnád, the country changes: the flat, sandy tracts of the south-coast of Madura are left behind, and so are the numerous tanks and the long collecting channels, which are spread over the impervious black (cotton) soil, and the tracts of rice-fields below them.

On entering South Tanjore, though still low and flat, the slope of the country from the sea inland increases to nearly 10 feet per mile. Numerous ridges and depressions, some of them 50 feet in depth, run from W. N. W. to E. S. E.; the former well covered with valuable trees, and the latter with patches of cultivation (*vayal*).

This change of country is sufficiently indicated by the character of the place-names. There are very few towns or large villages, and the village-lands are more like parishes with numerous small hamlets, each bearing the same village name, but distinguished by a suffix indicating the relative position of each within the parish limits.

The following facts may be gathered from an inspection of the map (Indian Atlas Sheet No. 80) :—

(*a*) The absence of rivers and irrigation-works.
(*b*) The absence of hills, mounds and rocks.
(*c*) That the country has been to a great extent jungle (*kádu*=wilderness), and occupied by rude, unruly tribes, such as Kallan, Pallan, Valiyan, and Védan.
(*d*) The considerable number of places termed Agrahárам, Mangalam, Pattanam, Pettei, Santei, and Vayal, indicate the presence of a fair proportion of more civilized folk, and tell of trade, agriculture, and brahmanical influence.

Whilst the vegetable kingdom appears to contribute liberally to the onomatology of the district, the animal kingdom is but scantily represented by the peacock, fox, crane, and a few more.

Note regarding the accentuation of the letters O and E in the orthography of South Indian place-names.

The long and short sounds of these vowels, *o* and *e*, are of such frequent occurrence in the Dravidian (*i. e.*, South Indian) languages, that unless some means of distinguishing them are adopted, mistakes as to the meaning and origin of the word in which they occur are unavoidable. It is, therefore, the universal practice amongst writers who have to represent Dravidian words in the Roman character, to accentuate those vowels when long.

A few specimens are given below of words similarly spelt, which require accentuation to distinguish the pronunciation and meaning :—

mel	=	soft.
mêl	=	above.
pen	=	a female.
pên	=	a louse.
veli	=	the air, the open.
vêli	=	a hedge.
veru	=	empty, void.
vêru	=	other.
vetti	=	cutting.
vêtti	=	a (man's) cloth.
kodi	=	a flag, steamer.
kôdi	=	a point, end, score, &c.
kodu	=	give.
ködu	=	a horn, peak.
kottei	=	a knob, knot nut.
köttei	=	a fort.
porakudi	=	back-house.
pörakudi	=	war-house.
totti	=	a pail, trough.
tötti	=	a sweeper.

In a list of South Indian names drawn up with a view of shewing their origin and root meaning, the accentuation of *o* and *e* when long (as well as of *a*, *i* and *u*, which have been allowed to require accentuation by writers of the North Indian languages) is really indispensable, and has been adopted in the following list of place-names, but not upon the chart accompanying, for want of the necessary authority.

It is hoped that the strict rule for North Indian orthography will be relaxed in this list of South Indian place-names.

B. R. BRANFILL, *Lieut.-Colonel,*

Deputy Superintendent, Great Trigonometrical Survey,

In charge Madras Party.

II.—Extract from the Narrative Report, dated 26th September 1877, of Lieutenant H. J. Harman,, R. E., Assistant Superintendent, 2nd Grade, in charge Assam Valley Triangulation.

2. At the close of the field season, 1875-76, the principal series was complete up to the side " Dibrugarh—Khalkata," the preliminary work of two triangles had been done, the right flank rays of the series were carried up to near the Revenue Survey Pillar at " Poba," and three post stations had been built. Of the branch series to " Jaipur," one final ray had been cut, eight trial rays run (which determined the positions of the six stations of the Series in the plains) and one post station built.

3. Accompanied by Mr. J. F. McCarthy and a small body of men, I left Gauháti on the 16th October, reaching Dibrugarh on the 23rd October.

By 10th November we had cleared three old rays near Dibrugarh, repaired three post stations, obtained angles to the snowy peaks and hills visible from Dibrugarh, and cut two final rays of the " Jaipur Series." One of these rays had to be cut open to the sky throughout its length ; on the other one the trees closed in overhead: every endeavor was made to avoid felling any trees whose trunks did not come within six feet of the centre line of the ray ; thus very few fine trees were cut down. The forest was in places interlaced with dense masses of creepers, and heavy storms of wind sometimes caused these creepers to drop down and shut up the ray. On these two lines there fell about four miles of forest, most of it belonging to tea estates ; as the forest was close to Dibrugarh, compensation was demanded for the timber cut down. The satisfactory settlement of these claims took up a great deal of my time. On the branch series to Jaipur many miles of line passed through tea estates, and I am glad to say that the ray-cutting parties were not interfered with in their work, Mr. O'Sullivan taking special care to do the least possible damage.

4. The preliminary work already done on the Jaipur Series, detailed in paragraph 2, had been executed by Mr. O'Sullivan. To carry up this triangulation to the side, whence it was to be extended direct on to the Naga Hills above Jaipur, required the construction of five post stations, the final carrying of six rays of which the trial lines had been run, the cutting of three new lines, and the observing the angles of the triangulation. To Mr. O'Sullivan was assigned this work. He broke ground on the 10th November, and was employed on this series throughout the whole field season, except for a week, when he observed at Dibrugarh the angles to the Nari H. S. and Dipa H. S. of the principal series.

The extension of the principal series up to Poba was entrusted to Mr. McCarthy, who left Dibrugarh with his detachment on the 10th November.

5. I started from Dibrugarh for the Khalkata Station of the principal series on 12th November, observed principal angles at three stations, and angles to hill peaks at two stations; then I went to Poba, whither I had sent the writer of the party (Baboo Zuhur-al-Islam) and a detachment of men, with instructions to make a road from the Mekla Station to the Poba Station and begin the line-cutting of the preliminary series between Poba and Sadiya. When I reached Poba, I found that considerable progress had been made. The preliminary series was carried up from Poba to the line Dibangmuk—Napsur by the 1st January 1877. A trial line was also cut between Sadiya and the Dikrang martello tower, the final ray being afterwards cut by the Topographical Survey Party under Lieutenant Woodthorpe, R. E. During November and December I observed from four stations to all the hill peaks visible from those stations. I had very bad luck in my work to hill peaks, considering the time I devoted to it. I made many fruitless journeys, and lost many days in my endeavors to get angles to the snowy ranges from stations favorably situated for the intersection of the peaks; not that there was any lack of splendid days for peaks during the season, but I got so few chances when I was available for the work.

6. One of the lines cleared by Mr. O'Sullivan passed through a heavy forest in which a gigantic India-rubber tree took a party of 20 men nearly two days to fell, and then it took 10 men a whole day to settle down the debris. Big trees are rare in the plains of Upper Assam—only one other was met with this season, it was on the line Sadiya—Manabum H. S.; luckily the trunk was a mere shell, for it measured 43 feet in girth at 4 feet above ground.

7. In January I sent eight men with an elephant to make a foot-path of about 4½ miles along the bank of the river between two stations; after four days the men returned and reported the path cut; also, that a great deal of very heavy cane had been met with through which the elephant could make but little way, and the path would speedily close up. A week passed, and I had occasion to send along this path a signalling party, and though the men started early, they did not get to the station 4½ miles distant till the following morning. Some days afterwards, two of them returned in a boat for provisions, and started back by the foot-path in the forenoon; but they again past a night in the forest. This incident serves to show how seriously a cane jungle hinders our progress; the natives with their bare legs are obliged to go through it very slowly, and deal with it cautiously.

8. At one station, with a party of 10 men I built a scaffolding of 75 feet in height in three days. This lofty field observatory is a very stiff and substantial structure, 8 feet square at top, and although bamboos and cane (of which it is constructed) rot with surprising rapidity in Assam, I hope that it will need but little repair next year to make it answer its purpose.

9. In the narrative report for the year 1875-76, it is stated that the "Abar" tribes objected to the occupation of a couple of peaks (Dipa and Nari) on the outer ranges north of the Brahmaputra river, one of which was intended to be a station of the principal series. Arrangements were made for a force of 100 men of the 44th Sikh Light Infantry to escort the Survey Party to the hills. Our orders were to confine the survey work to those two points, not to make excursion for sketching purposes, and, as far as possible, to avoid all villages.

The 15th of January was the date fixed for the small expedition to leave Dibrugarh; it was estimated that the troops would be absent one month.

We reached the top of the "Dipa" hill on the 18th January. It was cleared sufficiently for the trigonometrical work, a pucka station was built, the angle required was observed, all possible sketching done, and we left for "Nari" hill on the 21st January.

Dipa hill is nearly 3,000 feet high; we had to find our own way up it. The spur selected to ascend by turned out to be a very narrow, serrated ridge, and very steep, and had it not been for the dense forest, I much doubt whether we could have got up the hill by that spur. The station was about 4 miles from our camp on the Diman river. The trees on the hill top were festooned with masses of great creepers, many of which yielded a good supply of water; nearly a pint oozed out of a yard's length of one of them.

Major Clarke, B. S. C., Deputy Commissioner of North Lakhimpur, kindly arranged for some road cutting, which proved of great service to us.

To get to the Nari hill, we waded for 12 miles up the Dipi river, thence cut a road ¾ of a mile long to the foot of the hill, and struck a wild elephant track which led nearly to the top. The station was about 6 miles from the camp on the Dipi river. The Nari hill is nearly 3,000 feet high, and easy of ascent. The summit was cleared, and the station built by 30th January.

Shardon Rai Chand Bahadur, Seristadar of the Court at Dibrugarh, who was detailed to accompany the party, gave us most energetic aid, and through him I got the services of 25 "Miris" to help me to clear the Nari hill.

I encamped on the hill top from the 30th January to the 6th February. The weather was very rainy, and we were visited by some appalling thunder-storms. We heard on two days the volley firing of the squads at rifle practice on the ranges at Dibrugarh, distant 25 miles as the crow flies. The observations were finished on the 12th February, and then the troops returned to Dibrugarh.

To Major Robertson, B.S.C., my best thanks are due; he gave me every help, the arrangements were most convenient, and my progress greatly facilitated; not the slightest hitch of any nature occurred.

Colonel Nuthall, B. S. C., Commanding at Dibrugarh, was most kind in giving us every assistance; he came on one occasion to "Dipi Muk" to meet us. The jungle at the foot of the hills is tremendous.

The hills are clothed with magnificent timber, and we saw many fine rubber trees which had never been tapped. The formation of the outer ranges is of coarse-grained sandstone, soft and friable. The country between the outer and the first high range is full of low hills heaped together in the wildest confusion, showing hundreds of small precipices of various shades of red, white, and brown. From the Dipi and Nari hills only a few tiny patches of cultivation were visible. The "Aboors" did not put in an appearance, and, excepting a few well-known men, we saw very few of them. A sketch was made of 100 square miles of plain country and 300 square miles of hills, hitherto unsurveyed. A pucka platform was built near the mouth of the Dipi river, and fixed by intersection from the Nari and Dipi hill stations.

11. From the 9th to 31st March, rain fell on every day except two; excepting those days, the tents of the party were never dry. The greater part of the rain fell late in the evenings, yet we had not altogether twelve hours of sunshine after the 9th March if we leave out the two days before mentioned. Fortunately most of the lines of the series being short, it was found that by taking special precautions in setting the signals, there were often short periods during the day when the gleam from the silvering of the heliotropes could easily be seen in the telescope, despite the absence of sunshine. Thus by watching my opportunities I managed to observe angles from 13 stations during the month. Mr. McCarthy carried two trial rays, two final rays, and built one post station in March. He was not well during this month, yet he worked very hard: one day a tree accidently dropped on to his head, and I am sorry to say he was confined to his tent for three days in consequence.

The filling of the nullahs; the rain, absence of sunshine, and appearance of myriads of leeches, seriously impeded progress and caused the line-cutters to suffer severely. The work on the delta of land between the Dibang and Brahmaputra rivers was most difficult, the lines in the forest about the Dibang-muk station rarely progressed as much as 400 yards a day; so dense is the jungle and so numerous are deep nullahs choked with the heaviest growth. The Dibang-muk station stands in the depth of the forest; around the station a considerable area had to be cleared to admit the sun to the station so as to allow of signals being shewn during the greater part of the day: on to this station, converge 5 lines. A visit to this place would enable one to form a good idea of the enormous amount of labor required on parts of the preliminary series. The station is prettily situated, and the platform is high enough to give glimpses of the river through the gaps, and of the snowy ranges peeping over the trees; sometimes the lines are filled with very beautiful sunlight effects.

12. On the 1st of April I crossed the Brahmaputra in a heavy gale of wind, a great storm raged over the Dihang river, and the phenomenon of a water-spout was witnessed. On the afternoon of the 2nd April the observing overtook the work of the preliminary series, and I had made my arrangements to go to Sadiya, when a khalassie came in to report that at noon of the preceding day our 80-maund boat was lashed alongside the bank at a spot about 30 miles below my camp (Dibang-muk), when a great wind carried off the heavy roofing of the boat and then the waves swamped and sunk the boat in deep water. On board was a tin-box containing the duplicate set of computations of the recess season 1876, together with other papers. Taking with me a few men, I started down-stream by boat at midnight of the 2nd; the night was rainy and pitch dark, and we had several escapes from snags, so we stopped on reaching the rapids below Poba stockade and waited for the dawn of day. On the evening of the 3rd the sunken boat was dragged out of the deep water, but in the night the river rose, ran like a sluice, and the boat broke loose and filled with sand. Our efforts to move it on the 4th were ineffectual, so I left the spot on the 5th and reached Sadiya on the 6th, having lost four splendid days on my trip. Three weeks afterwards, a "Miri" got up the tin-box with a spear, and I was glad to find that the contents had suffered no material injury.

13. Lieutenant Woodthorpe, R.E., in charge of the Topographical Survey Party working in the Singfu country north-east of Sadiya, had selected a trigonometrical station on the Mánabum hill (height about 600 feet, 18 miles east of Sadiya) which it was necessary to incorporate with the principal triangulation. I found the station at 112 feet above the top of the hill in the branches of a gigantic India-rubber tree. The station is 4 miles east of the Tengapani, a river full of fine rapids which can only be shot in small canoes. The morning I visited Mánabum was rainy, the leeches were most formidable and indescribably numerous, especially where the path had been cut through bamboo forest. One man was lame for a week from the leech bites of that morning.

On our return from the hill the sun was shining fiercely, and not a leech could be seen. The natives smear over their legs a mixture of tobacco juice and lime which gives protection against the leeches, but in the wet jungle the stuff quickly gets washed off.

I met Lieutenant Woodthorpe, R.E., on the Tengapani river, to arrange with him the connection of our respective triangulations. I got back to Sadiya on the 20th April, completed the angles at 3 stations, and opened out the rays to the Mánabum hill station by the 29th April. Only one angle was measured to the Mánabum hill station on account of the unfortunate premature return of my signaller from that place; but Lieutenant Woodthorpe got a few observations at Mánabum to my two stations in the plains: thus a preliminary value for the Mánabum hill station has been obtained.

At Bhati Sadiya station on the 29th April I got a touch of the sun and was seized with severe illness, and consequently getting to the Dibang-muk and Napsur stations and observing the remaining angles at those places, gave me some trouble.

14. Lieutenant Woodthorpe, R.E., was journeying to Dibrugarh after the close of his field season's work when he heard that I was ill. He came to Napsur station and stayed with me till he had seen me through my remaining work on the principal series; and had it not been for his kindness in staying with me, I doubt if I could have completed it.

15. It was unfortunate that so few angles of the Jaipur Series were measured as the work progressed, it resulted in our being unable to finally measure all the angles of the series by the close of the field season. Mr. O'Sullivan placed signallers on "Hilika" station, who were threatened by the "Nagas" and turned off the hill, so I applied for and was given a police force to prevent further annoyance. Having recovered somewhat from my sickness, I left Dibrugarh for Jaipur, accompanied by Mr. McCarthy, on the 7th May, cut the line Timolikhat to Hilika, visited Deohal hill on which Mr. McCarthy erected a 50 feet bamboo scaffold, completed the observations at Hilika hill station, Timolikhat station, and all the angles but one at the Bamonikora station, by the 14th May.

May was a very wet month, the country got deeply flooded; it once took us 7 hours to wade along 5½ miles of path. Following me on that occasion, were 3 elephants very lightly laden, one of which fell into a hole and would have drowned but for the promptitude of a khalassie who got down and cut the girth ropes with his "dao" On the night of 16th May I became very ill and rapidly got extremely weak. It rained almost incessantly from the evening of the 16th to the 20th May; on the latter day the ground on which my camp stood was swamped, and I was carried to the Madarkhat station. There I met Mr. McCarthy, who had been hard at work, carrying a line through the flooded jungles. After making an effort to observe angles at the Madarkhat station, I made over the work of observing to Mr. McCarthy, who got measures of the angles at Madarkhat station on the 21st May. He closed work and marched into Dibrugarh on 23rd May. After the 8th May, Mr. O'Sullivan got angles at 2 stations and observed a set of vertical angles at the Madarkhat station; he marched into Dibrugarh on the 22nd May.

The weather from the 16th to the 25th May was simply dreadful, the large amount of rain falling fairly stopped our work.

16. The whole party left for Gauháti by steamer on the 26th May. After settling the affairs of the party, I took leave on medical certificate on the 10th June. Messrs. O'Sullivan and McCarthy went into recess quarters at Shillong.

III.—Extract from the Narrative Report, dated 20th September 1877, of H. Beverly, Esq., Surveyor, 1st grade, Officiating in charge of the Burma Party.

2. The party continued in recess quarters till the end of October engaged in the computations of the previous season. Mr. W. Beverley, in charge of the party, returned from privilege leave on the 28th October, and after taking over charge he proceeded on the 7th November to Rangoon, to resume field work, leaving Messrs. Mitchell and Collins to follow him by the next steamer. He remained in Rangoon from the 8th to the 17th November, organizing the field establishments and completing the charts and computations of the late recess.

3. During season 1875-76 the field work of the party was as follows:—

First.—A chain of secondary triangles (designated "Myanaong and Cape Negrais Triangulation"), emanating from the Eastern Frontier Series, was carried south, by Mr. W. Beverley, through the Henzadá district, and terminated for the season on the side Gnaw-Lekho, in the Bassein district. A second chain (designated "Prome, Thayetmyo, and Tonghú Triangulation"), also emanating from the above series, under Mr. J. Low, was carried north towards the frontier, and terminated for the season on the side Minúkídong-Membhadong, in the Thayetmyo district.

A third chain (designated the "Rangoon and Coast Triangulation"), emanating from sides of the Eastern Frontier Series in the Shoaygheen and Amherst districts, was commenced the previous season, and the work was finally brought up last year to the side Mengálón to Lekheik.

4. During the field season 1876-77 the programme was as follows:—

Mr. W. Beverley to continue the chain of triangles towards Cape Negrais, and also to determine the positions of the towns of Henzada and Bassein. Mr. Low to continue the Prome, Thayetmyo and Tonghú Triangulation in an easterly direction as close to the frontier as practicable.

Mr. J. W. Mitchell was ordered to take up a chain of triangles from the side Myáyábengkyó-Théyékhú of the Eastern Frontier Series (which was approximately laid out last field season) in a northerly direction, through Tonghú till the frontier was reached, and then to proceed westward and connect with Mr. Low's triangulation. Mr. D. J. Collins to continue the Rangoon and Coast Triangulation towards the Kristna Shoal light-house. But as this work could not be resumed till the country was dry, about the beginning of January, he was ordered to determine the position of the small town of Minjí to the south-east of Myanaong, and to complete the triangulation to determine Henzadá, thereby relieving Mr. Beverley, who could take up the extension of the first chain of triangles.

5. Mr. Beverley was engaged on the Henzada Branch Series, where he took observations at five stations and at one hill station of the main triangulation, thereby determining the positions of several buildings in Henzadá. This work occupied him nearly to the end of December. He next took up the extension towards Cape Negrais. Mr. Beverley carried this triangulation 36 miles in a direct line bringing down the triangulation to the civil station of Bassein, and likewise determining the positions of some important points in that station. He had unusual difficulties to contend with during the field season. The course of the Cape Negrais Triangulation is selected with one flank on the low hills on the Arracan Yomas, and the other flank in the plains, to avoid enhanced expense and delay had the triangulation been wholly in the plains or on the uninhabited hills. In the plains advantage is taken of isolated pagodas on one of the platforms or ramps of which the station is selected, thereby raising the station 20 to 30 feet above the surrounding country. The hills in the Bassein district are uninhabited, and are never visited by any of the inhabitants of the plains to the east. They are also of almost equal elevation, flat-topped and covered with a dense forest; hence the difficulty in finding the particular hill selected in a large block: to which is added the unwillingness of the villagers to leave their homes and be away at night. The difficulty is to retain them for more than a day or two. The hills generally require extensive clearing before they can be used for trigonometrical purposes. In the plains also great difficulty is experienced in carrying lines through swamps. Mr. Beverley lost much valuable time owing to these swamps and the low forest-clad hills. Mr. Beverley closed work on the 21st April and returned to recess quarters at Moulmein on the 2nd May. On the 18th idem, having obtained furlough, he made over charge of the party to me.

6. Mr. J. Low, Surveyor, 2nd grade, rejoined from four months' private leave at Rangoon on the forenoon of the 20th November, having received instructions to extend his last season's triangulation from Thayetmyo along the frontier towards Tonghú; he left Rangoon by steamer and arrived at Thayetmyo on the 29th November.

7. Mr. Low extended the secondary triangulation 44 miles by six stations, forming two figures, terminating the series for the season on the Pegu-Yoma mountains. Much of his time was taken up in marching, and he had to visit his stations twice or three times—once to select the station, and a second time to observe the angles from it. In a wild country like Burma, with flat-topped hills of almost equal elevation, covered with dense forest, far removed from the nearest villages and nothing to distinguish one hill from another, it is very difficult to select stations. The Surveyor finds it impossible to send any one of his establishment on this task merely by pointing out the hill to him; he has to visit the hill himself, select and clear it, and return to take observations to it. Mr. Low has also determined a few peaks on the Arracan and Pegu Yomas and a few other points, the heights of which he has also determined. I think Mr. Low's out-turn of work is satisfactory.

8. Owing to the unhealthy nature of the country Mr. Low worked in, his health has suffered; he had to leave on medical certificate for six weeks during the field season, and since his return to recess he has suffered repeatedly. He has been under the Civil Surgeon's treatment for some time, and is at the present moment far from well.

9. Mr. J. W. Mitchell, Surveyor, 4th grade, left Moulmein for Rangoon on the 9th November. On the 13th he started for Tonghú to take up the triangulation to Tonghú from a side of the Eastern Frontier Series, some of the stations of which had the previous season been prepared by him. Mr. Mitchell extended the triangulation to the Burmese frontier, a distance of 56 miles, and determined the positions of three points in the station of Tonghú. By the middle of February there was a break of only 50 miles in the triangulation between the work of Messrs. Low and Mitchell, which Mr. Beverley considered would require one Surveyor to complete during the remainder of the field season with favorable weather. He, therefore, requested Mr. Low to form the connection and Mr. Mitchell to return and join him, to assist in the Cape Negrais Triangulation and to determine points in the station of Bassein. Unfortunately, Mr. Low was just then taken ill, as previously stated. On his return from sick leave, Mr. Low was only able to complete the angles he had left unfinished. Hence there remains the break of 50 miles between Mr. Low's and Mr. Mitchell's triangles, which, it is hoped, will be completed next field season. Mr. Mitchell meanwhile left Tonghú for Bassein, and arrived at Rangoon on the 15th March. There he waited a few days to entertain some men, and arrived at Bassein on the 22nd March. Mr. Mitchell observed both horizontal and vertical angles at two stations in the town of Bassein, and five in the Cape Negrais Triangulation. Mr. Mitchell states that his stations on the Tonghú Triangulation were all in uninhabited hills, and he experienced great difficulty in visiting them. Mr. Mitchell closed work on the 22nd May and arrived at Rangoon on the 24th May. At Rangoon he was attacked with cholera, which weakened him considerably, thereby preventing his return to recess at Moulmein till the 13th June. In Moulmein, too, Mr. Mitchell has suffered from illness. He was attacked with dysentery some time ago, and though under the Civil Surgeon's treatment, he has not yet quite recovered from it. His progress, I think, has been satisfactory.

10. Mr. Collins left Moulmein on the 9th November, and up to the 17th idem he was engaged in current office duties with Mr. Beverley, whom he accompanied to Henzada. Mr. Collins' camp was sent by land to Minji, which small town he was requested to determine the position of. Meanwhile he assisted Mr. Beverley at Henzadá till the 25th November. He left by steamer on the 27th November for Minji, where he arrived the same day. On completing observations at Minjí, he returned towards Henzadá, having been instructed to observe at the two stations to determine the position of the great pagoda of Henzada.

12. Mr. Collins during the next two months protected and transferred to the care of the local officials six principal stations of the Eastern Frontier Series. Besides these, he visited Yongdong near the town of Prome. This station he reported had been removed, and a large hole indicated the site of the station. He also attempted to visit the trigonometrical station of Moditong, in the centre of the Arracan Yoma mountains, but the coolies refused to go. He returned to Rangoon by steamer on the 16th March to resume the triangulation along the coast. He was ten days in Rangoon entertaining men and waiting for his theodolite. On the 27th he left by boat to visit the two stations of Lekheik and Mengalon to start the Coast Triangulation. He was only able to visit these two points and construct a ladder up the former, when, on the 10th April, he was taken ill and returned to Rangoon, where he obtained a medical certificate from the Civil Surgeon and closed work for the season. Mr. Collins was on three months' privilege leave, from the 13th April to the 13th July.

16. There now remains a break of 50 miles in the triangulation along the frontier, which will probably be completed by one assistant next field season. The Cape Negrais Triangulation of 80 miles to the Alguada light-house and the extension to the Krishna Shoal light, about 70 miles, are likely to occupy two officers two seasons.

17. The Krishna Shoal light was washed entirely away during the present monsoons. As this point is important for shipping, a new structure will probably be erected by the time the triangulation is brought down to it.

21. The area triangulated by this party during season 1876-77 is 4,645 square miles, at a cost of Rs. 38,517-14-3, giving a rate of Rs. 8-4-8 per square mile.

IV.—Extract from the Narrative Report, dated 1st October 1877, of Captain J. Hill, R.E., Assistant Superintendent, 1st grade, in charge of the Eastern Frontier Series.

2. On returning to Bombay from furlough to Europe, and receiving orders to assume charge of the Eastern Frontier Series in Burma, I proceeded at once, *viâ* Calcutta and Moulmein, to Tavoy, where I landed on the 9th of last March, and where elephants sent by Mr. H. Beverley, were awaiting me. The head-quarters camp happened to be only about a week's march from Tavoy. I found it on the 16th March just arriving at Toungthúnloun H. S., and on the following day I assumed charge of the Party.

3. When Mr. Rossenrode was retiring from Government employment, Mr. H. Beverley received the officiating charge of the Party and retained it until my arrival. I then found his observations were almost completed for the season; so as it was too late to detach him for other work, I decided on allowing him to finish what he had carried on so far. The whole credit of the field season's principal operations therefore belongs to Mr. H. Beverley, and as my information regarding what took place before my arrival has been chiefly derived from him, he has at my request drawn up the following narrative statement of the season's work :—

(*b*). "On the 1st November this Party comprised three Surveyors, *viz.*, myself, Mr. J. C. Clancey, and Mr. J. O. Hughes. I purposed resuming myself the final operations suspended on the setting in of the rains, about 60 miles south of Moulmein; while Mr. Clancey should extend the approximate triangulation, which last year closed with the Myándoung figure in the Tavoy District. Mr. Hughes with a small party I wished to employ on secondary operations, determining the positions of Phayátounzú (the Three Pagodas), the town of Yeh, &c. All my arrangements were in a meausure temporary. I was informed that Captain J. Hill, R.E., was appointed Mr. Rossenrode's successor, and would arrive in India about the end of January. I presumed he would, probably within a month of that date, join the Party, when as a matter of course the arrangements would have to be altered. On his assuming charge on the 17th March, he considered it unnecessary to alter existing arrangements for the short time that remained for field operations; hence the above arrangements continued to the close of the season, and at his request I continued taking final observations for the remaining three stations.

(*c*). "Mr. Clancey was requested to leave Moulmein by the Tavoy steamer on the 7th November, his camp having left overland for Tavoy on the 24th October to await his arrival. Mr. Hughes continued with me to bring up the office work till the 15th November: he left Moulmein on the 22nd idem to take up secondary observations. During the first week of November the signal parties were sent to their respective stations, some overland, and others by boat. At the same time the tindal with fifteen men was ordered to clear the path from the Moulmein and Amherst road, the first station of observation. A week later, on the 14th November, I despatched the main camp, theodolite and elephants for the above station, where they arrived on the 28th idem. A few days later, after despatching the preliminary chart and records to head-quarters, I left by boat for Keoktagá, arriving at that station two days after my camp.

(*d*). "During the observations at this and the next station I noticed certain discrepancies in the horizontal readings of the 24-inch theodolite, which I could not for some time account for, the change affecting only one station at a time occasionally. I subsequently found they were caused by a slight lateral motion on the telescope, from its revolving unevenly in the Ys. As I did not know how to remedy this, without perhaps putting the instrument out altogether, and as only occasionally these differences occurred, I left it for Captain Hill to rectify on his arrival.

(*d*). "Consequent on the paucity of villages in the tract of country wherein our operations lay this season, and the unwillingness of the inhabitants to leave their homes for more than a day or two, I deemed it expedient to entertain a large number of men in excess of our usual numbers for the cutting of roads, transporting of baggage of signal parties, &c. I also purchased large quantities of rice and paddy for the camp, enough for a supply for two months, by which time I expected to enter the inhabited tracts of the Tavoy District. A portion of these provisions was transported by boat to the village of Onbengkweng, where rice could not be purchased except at the exorbitant rate of about 7 seers per rupee. These arrangements certainly increased the working expenses of the Party, but they obviated failure. The number of villages met with on the line of march, throughout the season, was only 23, including the town of Yeh, and but four large villages, the rest being hamlets of from 4 to 8 or 10 huts, from which we could not expect labor or provisions to meet the demands of such a large camp.

(*e*). "The field season lasted five months: of this, 80 days were employed by the main camp exclusively in marching, there being no direct route from station to station, the time occupied in marching to each station being from 3 days the least to 10 days the largest number of stages; this could not be helped in a country which is almost entirely uninhabited, and circuitous routes had to be taken. I was fortunate this season in not being delayed much more than a fortnight from hazy weather, which in former seasons generally deterred operations for a considerable length of time. A party of 15 men under the tindal, assisted with such coolies as could be procured from the villages, was employed throughout the season to precede the main camp, clearing the path and making it passable for the large theodolite and for elephants, a task accomplished with the least possible delay to the camp."

4. The foregoing statement refers principally to Mr. Beverley's own operations. His remarks upon the instructions he gave to Messrs. Clancey and Hughes, and the manner in which his instructions were carried out, are as follows :—

Mr. J. C. Clancey.

(a). "Mr. Clancey was deputed to extend the approximate triangulation; he left by the steamer of the 7th November, and arrived at Tavoy on the 8th.

(b). "At the close of last field season, the approximate triangulation had been brought down to the Myándoung figure, of which one station had still to be selected and one other built: two more stations in advance had been visited, and one of them, Toungshún, built. Mr. Clancey was requested, before commencing work, to visit Toungshún and another hill near Tavoy, and thus proceed upwards to the base of his operations, by which means he would obtain a very good knowledge of the country. He was also requested, if possible, to keep on to the main land and avoid visiting the islands, which would, I considered, be a source of considerable delay and expense.

(c). "By the 27th January Mr. Clancey had laid out a satisfactory triangulation, comprising (1) the completion of the Myándoung figure by the selection of one new station; (2) the completion of a quadrilateral which had been partially selected last year; and (3) a hexagon round Toungshún H. S. of the previous season's work. Two of the stations of this last figure were on islands, known as the Moscos, averaging about 20 miles from the opposite mainland stations.

(d). "Mr. Clancey's reasons for making use of the islands were, that he found it impossible to continue the triangulation on the mainland, since he could not get suitable sites on the frontier range, and the country to the east was uninhabited, and under these circumstances I think he was justified in carrying the triangulation partly on the mainland, and partly on the islands.

Mr. J. O. Hughes.

(e). "Mr. Hughes left Moulmein by boat on the 22nd November for Amherst, and thence by land to Yeh, from which place he was requested to cut a road for the 24-inch theodolite and the elephants to Sedoung H. S., a road which Mr. Rossenrode had found it impossible to cut the previous year, through the duffadars he repeatedly sent with that object failing each time on account of the difficulty in getting the villagers to work. From Yeh to Sedoung, a distance of nearly 30 miles, the country is uninhabited, with the exception of a few huts about half-way, and coolies could not be procured. Mr. Hughes completed this task by the middle of December, not, however, without my having to send to his assistance all the men detached from the main camp for general road-cutting.

(f). "The secondary work upon which Mr. Hughes was afterward employed was the determination of the position of Phayátounzú (the Three Pagodas), the well-known boundary between Siam and Tenasserim; also the determination of the position of the town of Yeh, and other points; which work, I expected, would employ him to the middle of February, when he was to join the main camp about the time of Captain Hill's arrival. I left it optional with him to determine the position of Phayátounzú either by a series, or directly from the principal stations, if visible. Mr. Hughes adopted the latter plan, and completed the necessary observations at one of the two principal stations chosen for the purpose. Unfortunately, when he arrived at the second, bad weather had set in, and long sides could no longer be observed. He remained on the spot as long as his provisions lasted, and then finding the haze did not clear, left the place and joined my camp on the 2nd March. Mr. Hughes was next detached to determine the position of Onbengkweng village and two pagodas in the Myándoung figure, which he accomplished and joined the main camp on the 17th March."

5. After Mr. Hughes had joined the main camp, as above stated by Mr. Beverley, I detached him—(1), to select and build a secondary station in a good position in the town of Tavoy; (2), to help Mr. Clancey by clearing two hill tops which Mr. Clancey had fixed upon as sites for principal stations; (3), to place a secondary station upon the well-known peak and land-mark Nwálabo (Ox's Hump). He selected and built the station in Tavoy, and made some progress with the clearing of the hill tops, when it became necessary, in consequence of the conclusion of the principal observations and the arrival of the main camp at Tavoy, to call in both him and Mr. Clancey. They reached Tavoy on the 22nd April, and the whole party (excepting the elephant establishment and some other men I thought necessary to leave behind) started for Moulmein on the 24th April.

6. During the recess the party has been chiefly employed in computing out the work done during the field season. A considerable amount of time has also been taken up in classifying and reducing to order the records of the party. The transfer of the principal stations in the Amherst district to local official protection, which was stopped by the late Officiating Deputy Commissioner of the district, has been proceeded with, and, owing to the willing co-operation of the present Deputy Commissioner, has been almost completed, only one station now remaining to be transferred. The performances of the 24-inch theodolite having been complained of by Mr. Beverley (*vide* paragraph (3) (*d*) I examined it, and finding the Ys not quite parallel to each other—a defect I had not the means of remedying—I sent it on the 10th July to the Mathematical Instrument Department, Calcutta, for repair. Mr. Beverley was quite right in bringing to notice the irregularity in the working of the theodolite, but I believe he was mistaken in thinking it was a new defect; for Mr. Clancey, who acted as Mr. Rossenrode's recorder, informs me that Mr. Rossenrode used to suffer inconvenience from irregularities of reading similar to those described by Mr. Beverley, and I find that, judged by the average triangular error and probable error of angles, the quality of Mr. Beverley's observations appears to be much on a par with Mr. Rossenrode's averages for the preceding three seasons: so that the instrument would not seem to have recently undergone any sensible alteration. On the 1st September, Mr. D. J. Collins, Assistant Surveyor, 4th grade, joined my party from the Burma party, Mr. Hughes being at the same time transferred to the latter party in his place.

7. During the field season observations were taken at twelve principal stations, all of which were duly closed except the initial ones of next season, and at six secondary stations. The average cost of the season's operations, as calculated by the departmental method, is Rs. 11-13 per square mile triangulated.

8. The several operations of the party have not been uniformly successful during the past season. The principal series has been well conducted by Mr. Beverley. His preliminary arrangements for taking the field were good, and proved quite successful. The quantity of principal triangulation completed only falls short by 558 square miles of Mr. Rossenrode's yearly average since the resumption of operations in 1873, and its quality, as already stated in paragraph 6, accords very well with that of Mr. Rossenrode's work during the same period. The area of the secondary and minor triangulation is the largest which has been obtained since the resumption of operations, and although the area of the principal triangulation does fall short of the average of the preceding seasons, that fact is accounted for and justified by the shortening of the time suitable for observations as the series proceeds southwards. No useful purpose seems to be subserved by trying to continue principal observations in Southern Burmah beyond the early part of April, by which time the last break in the hot weather haze may be expected to have taken place. Work was, therefore, closed at the time already mentioned, and I consider the out-turn very creditable to Mr. Beverley, especially as, owing to the great length of the difficulties and circuitousness of the routes, he was only able to spend 44 days in actual observing out of a field season of 156 days' duration. It is to be regretted that Mr. Hughes failed to determine the position of the well-known "Three Pagodas" which are situated on the road from Moulmein to Bangkok at the exact spot where it crosses our frontier. Although the pagodas are now in ruins, as a boundary mark they are very important, and their position ought to be fixed at the first available opportunity.

V—Extract from the Narrative Report, dated 21st September 1877, of Captain M. W. Rogers, R.E., Offg. Deputy Superintendent, 3rd grade, in charge Jodhpore Series.

The party took the field in October 1876: the first detachment under Messrs. Price and Torrens left on the 16th October, and marching direct to the series, commenced work on selection and building. The main party left Aboo on the 23rd October, and marched to Chachra, in Thar and Párkar, and thence to Rojhrá H. S. of the Karáchi Series, one station of the initial side of the new Series, "The Eastern Sind" principal observations were commenced there on the 20th November: from that date the observations were carried on continuously through the Thar and Párkar district of Sind, the Khairpur State, and into Jeysulmere, and were closed at Dhanono H. S. on the 18th March.

The weather was, on the whole, very favorable for observations until March, when, as usual in the desert, high winds and dust-storms commenced and made observing difficult and tedious. The following is a general statement of the season's work: 96 angles were observed at 28 principal stations, forming 4 hexagons, 2 quadrilaterals and a portion of another hexagon, fixing 26 new principal stations, embracing an area of 2,455 square miles, and extending the series 125 miles along the meridian. An azimuth was observed at Malár H. S. to two circumpolar stars. The approximate Series was extended north 98 miles. The position and height of the town of Umarkot were fixed, and 28 Revenue Survey stations were identified and fixed in height and position. Mr. Price was in charge of the approximate series: he selected 21 and built 10 principal and 7 secondary stations. completing the selection of the Eastern Sind Series. He, as usual, worked well and steadily, and accomplished a good amount of work, notwithstanding the drawbacks of an unfavorable country. Mr. Torrens took up the building on the principal series and completed 19 stations: he then closed 16 pricipal stations, and, in addition, he identified and marked a large number of Revenue Survey stations, and did a considerable amount of secondary triangulation to fix them.

The building operations of these desert series, involving in most cases the arrangements for making bricks, and in all cases a large amount of trouble and arrangement for the transport of bricks, stones and lime to the various sites from long distances, are of an unusually arduous nature; and I was much pleased with Mr. Torrens' exertions and general work, which fully entitle him to his promotion whenever the state of the Department permits. Mr. Prunty accompanied me as recorder during the whole of the observations, and after their completion, he closed seven stations of the principal series: he has worked very well, and is in all respects a good and useful assistant. The health of the party during the whole season was very good.

The country through which the series passed this season is, if possible, a more desolate tract of desert than any met with on the Jodhpore Series. Towards the south, in the districts of Thar and Párkar, the country is a succession of narrow sand-hills, sometimes of considerable height, running from south-west to north-east in perfectly parallel lines: they are higher, and the ridges closer together, than in Rajputana, and their sides are much more abrupt, and are channelled into ravines by the action of rain, and are covered with low thorn jungle. This makes travelling very tiring and tedious, as in marching, the village tracks had to be followed, and long detours made. This combined with the heavy sand and the continual up and down hill, caused the marching between stations to take up a considerable amount of time, 10 miles being a heavy march for loaded camels.

For about 50 miles along the western side of the series the country was inundated, and a vast expanse of water stretched as far as the eye could reach. The the ... of Umarkot, when

in marching

visited, was surrounded on two sides by water, which came up to the base of the fort. In the north of Thar and Párkar, and in Khairpur, and the western portion of Jeysulmere, a new phenomenon is met with. This is the "Draeus" or expanses of shifting sands, many miles in extent, and scattered here and there amongst the desert sand-hills, which are comparatively fertile, inasmuch as they are bound together and partially covered with coarse grass and stunted shrubs. These "Draeus" have no vegetation, and their surface is continually changing, and the sand in them is in one place scooped out into funnel-shaped hollows, and in another thrown up into beautifully-rounded hills. They were seldom crossed, but when necessity compelled a march over one of them, the road had to be inspected and prepared beforehand; and five miles was a fatiguing march. Curiously enough, in spots in these "Draeus," there are wells of water on small pieces of hard ground, which seem to be spared by the overwhelming sand, and in these wells the water is invariably good. The "Draeus" are very numerous, from about 26 North Latitude, and extend northwards some 75 miles. They impoverish the already sterile country, and I am inclined to think that the acme of desolation is reached in Eastern Khairpur and Western Jeysulmere. There are no crops, and the people live nearly entirely on milk in various forms, aided by a little "bajri" and "mot" imported from Sind in exchange for sheep. The inhabitants say that the "Draeus" travel gradually northwards, but very slowly. The summits of these "Draeus" rise to a considerable height, in many cases overtopping the sand-hills; and it became a matter of considerable difficulty to arrange the series, so as to avoid the stations falling on them. Notwithstanding all the care given to this, two stations had to be placed on them; every attention was given to building these stations with all precautions for stability, but I am doubtful if they will remain for long. The villages are of the same description as those met with in the other portions of the desert; the majority of the houses are merely wigwams of brushwood, a house with mud walls being a rarity, and brick and stone almost unknown. With the exception of Umarkot there was no place in the series worthy of the name of a town. The villages are nearly, without exception, built on the summits of sand-hills, and very often at some distance from their wells, which are, of course, in the hollows between the hills. The reason for this custom seems to be, that in the cold weather the tops of the sand-hills are considerably warmer than the valleys, where the cold is sometimes very great. The party experienced considerable trouble from the difficulty of procuring drinking water, especially on the eastern side of the series, near junction of the four States of Marwar, Jeysulmere, Khairpur and Thar and Párkar, where there is a tract of country about 30 miles broad by 40 long without any drinkable water, and it was with much difficulty that the necessary supply for the camp could be obtained.

Most useful assistance was rendered to myself and assistants in Thar and Párkar, Khairpur and Jeysulmere, where every thing possible was done by the local authorities to help my work, and my best thanks are due to Captain Crawford, the Superintendent of Thar and Párkar, His Highness Ali Murad of Khairpur, and the Jeysulmere Durbar. The total cost of the party for 1876-77, was Rs. 37,764-10-11, or Rs. 15-6-1 per square mile for the principal triangulation, or Rs. 14-8-10 for the whole triangulation. During the recess season, the computations of the season were brought up to date, and all the members of the Party were exercised daily in plan drawing, and had some instructions in the use of the plane-table.

VI.—Extract from the Narrative Report, dated 30th August 1877, of Major A. Pullan, S.C., Officiating Deputy Superintendent, 3rd Grade, in charge of the Kattywar Party.

Out-turn of Work.

The out-turn of work for season 1876-77 was an area of 1,716 square miles topographically surveyed, and 2,062 square miles of triangulation prepared in advance, while 752 linear miles of traverse were executed in order to demarcate the boundaries of the various States, and to check the plane-table survey of the country.

Expenditure.

The total expenditure for the survey during the past financial year was Rs. 70,082, and the out-turn of work finally completed was 1,716 square miles. Thus, deducting Rs. 3,600 cost of boundary survey establishment, we shew an average expenditure for finished work of Rs. 38-7 per square mile.

A portion of the country under survey was very wooded and hilly, and covered with intricate ravines, and the Surveyors could progress but slowly; added to this, I was deprived of the services of Messrs J. Peyton and W. Oldham, both good plane-table, Surveyors, who were transferred to other surveys, and had to replace them by Mr. Keating who, though a promising young Surveyor, had to be taught plane-tabling *ab initio*. One of my best native plane-tablers, Nilkant Vital, was also laid up before he had completed one plane-table, and taking his discharge from the Department proceeded to Poona. Mr. Gwynne, my best plane-tabler, was employed at my head-quarters from 4th December to 25th January, drawing the fair map of Sheet 38, which I had not been able to do more than commence in recess quarters at Poona; thus the smaller out-turn of work, as compared with season 1875-76, is, I think, fairly accounted for, and the amount executed this season will not be considered as insufficient.

Departure for the field.

The Party started for the field on the 25th October, the heavy baggage and horses with the subordinate native establishment proceeded, as in former years, to Gogo by "Patimar" boats, and arrived there on the 5th November after a rather rough passage. By the 15th of this month the various Surveyors were on their road to their work, I myself proceeding, *viâ* Jetpur, to Patanwao, at the foot of the Osham hill, while Mr. Gwynne proceeded with the main camp to Upleta and set to work at the drawing of fair Sheet 38, while he also employed his mornings in instructing Mr. Keating in the use of the plane-table.

Major N. Pullan.

I commenced the survey of Osham hill on the 5th December, and was employed on that and the survey of the Bhadar river, and in the instruction and daily supervision of two new plane-tablers, Mr. Keating and Narsu Dinkar, until the 24th December. The remainder of the field season I was employed in examining the plane-table Surveyors, besides making a twelve days' march about the Gir forest to examine the nature of the ground on which Mr. Bell was employed, and the character of his triangulation. On the 10th of April I reached Virawal, where I remained employed in the comparison of plane-table borders and miscellaneous office work until the last plane-table had been examined by me. I then started for Bombay *en route* to my recess quarters at Poona, which station I reached on the 14th May.

J. McGill, Esq., Assistant Superintendent.

Mr. McGill executed the triangulation of Sheets 54, 55 and 56 in his usual good style, and completing his work on the 15th March he proceeded to Virawal, where he occupied himself in bringing up angle books, preparing abstract of angles, and arranging triangle sheets for computation until the 11th April, when he left for Poona to assume charge of the Tidal and Leveling Party during the absence of Captain A. W. Baird, R.E. He was accompanied by Mr. Fielding and Head Sub-surveyor V. R. Gadboli, together with a small office establishment. On arrival at Poona, Mr. McGill opened office, and, in addition to his own special work, he superintended the preparation and projection of fair Sheet 50 of Kattywar. Mr. McGill's capacity for work and his untiring industry are well known, and it is only necessary for me to say that he worked this year as he has always done.

Mr. F. Bell, Surveyor, 3rd grade.

Mr. F. Bell was entrusted by me with the triangulation of Sheets 39 and 49; the area triangulated by him was 952 square miles, a portion of the ground being very thickly wooded and sparsely inhabited. As far as I can judge at present from the computations, the work seems of good quality, and Mr. Bell may be fairly said to have done a creditable season's work.

Mr. N. C. Gwynne, Surveyor, 3rd grade.

Mr. Gwynne was employed at my main camp from the 4th December to 25th January in drawing fair map of Sheet 38 of Kattywar. At the end of January he proceeded to take up a plane-table in the Alech hills, a very laborious and difficult piece of work, which he executed most skilfully, and which I found on examination to be most accurate in detail. Mr. Gwynne's out-turn of field work was 129 square miles. Mr. Gwynne worked, as he always does, hard and well.

Mr. W. A. Fielding, Assistant Surveyor, 2nd grade.

Mr. Fielding executed 173 square miles of topography in a very artistic and at the same time careful manner. I can only endorse again the favorable report I have always had the pleasure of making on Mr. Fielding.

Mr. G. Hall, Assistant Surveyor, 3rd grade.

Mr. Hall's out-turn of work was 204 square miles of topography, well surveyed and neatly drawn. Mr. Hall steadily improves, and is a very useful and willing assistant.

Mr. H. Corkery, Assistant Surveyor, 4th grade.

Mr. Corkery shews a good out-turn of 246 square miles correctly and neatly done. I regret that, under existing circumstances, it is useless to bring forward Mr. Corkery's strong claims for promotion to the next grade.

Mr. J. Keating, Assistant Surveyor, 4th grade.

Mr. Keating joined me in October, and after learning the use of a plane-table, he executed, under careful supervision, 149 square miles of correct and neatly-drawn work. Mr. Keating promises to make a good plane-table Surveyor, and his season's work is highly creditable to him.

Mr. V. R. Gadboli, Head Sub-surveyor.

Mr. Gadboli was employed at my main camp during the major part of the season in projecting points on plane-tables, and various miscellaneous duties. He executed 50 square miles of plane-tabling correctly, but his drawing was feeble and wanting in expression. Mr. Gadboli is more in his element in an office than when employed on out-door work,

The remaining 5 plane-table Surveyors all did good work, more especially Narsu Dinkar, who used a plane-table for the first time very successfully.

General health.

The season under review was a very healthy one, one or two cases of fever being all the sickness the party was troubled with. There was, I believe, a slight outbreak of cholera at some of the towns on the seaboard near Virawal; but, as far as the Survey was concerned, the general health was excellent.

Natural features.

To the south-west of Sheet 46 lies an intricate net-work of low ranges known as the *Alech* hills. They cover an area of 60 square miles, and are very sparsely inhabited. The few villages that there are, are placed in strong positions, and are surmounted by police towers, reminders of the wild times when the village watchmen, matchlock in hand, scanned hillside and valley with anxious eye, ready to mark an enemy's approach and give a timely alarm. Panthers abound in the narrow gorges of this range, but they are gradually becoming thinned as cultivation and civilization advance. In a narrow valley not far from Dhánk, and on one of the eastern spurs of these hills, are some very curious caves, now closed by order of the Superintendent of the Gondal State. Mr. Fielding endeavoured to enter and explore them, but found them thoroughly blocked up. These caves were a few years ago a private resort of the bands of wandering "Bharwattias" or outlaws, who infested the hilly country of Kattywar. These ruffians are even now occasionally troublesome in this part of the country, as, not further back than January last, a body of them attacked the small village of Virdi, in the Alech hills, and killed and wounded several of the people. Another peculiar feature in the country under review is the isolated basalt hill of *Osham*, which rises abruptly from the plain to an altitude of 1,032 feet above the sea. The hill is surmounted by a fort, once a very strong place, the ruined walls of which stretch round the hill, testifying to the strength of the defences in days gone by. Two good springs of water exist on the hill, one near a temple called Matri-ki-Devi being especially pleasant to the taste. Large blocks of obsidian, singularly like coal, are scattered about and crop up along the basalt and trap, and there are many external evidences that the hill is decidedly volcanic.

Towns of importance.

The principal towns which came within the area of country surveyed this season are—

In Sheet 46—

Bháyawadar—Population 5,563; under the jurisdiction of the Gondal State. The town is situated in a fertile, well-cultivated country, the population being chiefly Mussulmans, who do a thriving trade in cotton.

Jodhpur—Population 4,004; a town under the Jam of Nawanagar; of some importance.

Dhánk—Population 2,894; a town under the Gondal Durbar, formerly much more populous than now, and showing all the signs of a once important place now falling into decay.

In Sheet 47—

Upleta—Population 6,500; one of the largest towns under the Gondal Durbar, the people Mussulmans, Kunbis and Kolis, the trade of the place being in cotton.

Dhoraji—Population 15,562; under the Gondal Durbar; a very large cotton emporium. The Superintendent of Police, Gondal State, resides here; and there are also large cotton mills under European superintendence. Dhoraji is next to Jamnagar and Junagarh, the most populous town in Kattywar.

Kuntiyána—A town on the Bhadar river, and belonging to the Nawab of Junagarh; is a considerable place with a population of 9,912. The surrounding country is very well cultivated, cotton as usual preponderating.

Bántwa—With a population of 8,832; is a large place, the residence of a Babi Sahib, a connection of the Nawab of Junagarh. The little State of Bantwa is shared between three brothers, among whom the Bantwa Chief takes precedence.

Wanthali—With a population of 6,056; is a handsome town on the Uben River. It is surrounded by some of the most highly-cultivated ground in Kattywar. The town belongs to the Junagarh Nawab.

In Sheet 50—

Pátan—A fine, old, walled town on the southern seaboard of Kattywar, with a population of 6,856; is remarkable for its ancient and world-known Hindu Temple of Somnath. The temple is now a venerable ruin fast falling to pieces, and it would be creditable to the Junagarh Durbar if some steps were taken to arrest the progress of its decay. The sand is fast silting up round the black time-stained walls of the old city; in some places but a few feet of masonry are seen struggling out of the ever-increasing sand heaps. A sand-bar blocks the shallow mouth of the Harna river, and I never saw a place more thoroughly "a memory of the past" than Pátan.

Virawal—Five miles west of Pátan, with a population of 10,735, promises to be a place of importance. There is a good light-house on the pier, and if the Durbar carry out to completion their long-planned, but slowly-executed, break-water, the port of Virawal will afford a welcome shelter to the various crafts which ply along this rocky and dangerous coast.

These two towns are closely connected one with the other, and are commonly spoken of as *Virawal-Pátan*.

Rivers.

The rivers which are noticeable in this season's work are the *Moz*, the *Bhadar*, the *Ojat*, the *Uben*, and the *Harna*. The Moz and the Bhadar, the most considerable streams in Kattywar, have been already noticed in former reports. The Ojat, a deep stream with a considerable amount of water in many places, is joined by the Uben near Wanthali, and, after pursuing a tortuous course to the west, falls into the Bhadar river close to its mouth at Navi Bandar, on the shore of the Gulf of Cutch.

The Harna takes its rise in the heart of the forest-clad hills of the Gir, its rocky picturesque banks, covered with a dense growth of "Karanda" bush and "Jawbal," are the favorite haunts of the lion and the panther, and the beautiful stream after winding its way through a wild wooded country emerges for a few miles into the plain near Patan, and falls into the sea about a mile south of that ancient town.

TABULAR STATEMENT OF WORK EXECUTED BY THE KATTYWAR PARTY, GREAT TRIGONOMETRICAL SURVEY, DURING THE FIELD SEASON 1876-77.

Details of Triangulation.

Observer's Name.	Instrument.	Area triangulated in square miles.	Three Angles observed.							Two Angles observed.				Average No. of trigonometrical points per square mile.	Average No. of heights per square mile.	Pillars built.	Elements computed.	Remarks.
			No. of stations fixed.	No. of stations visited.	No. of triangles.	Triangular error.	Error per mile.	No. of heights.	No. of heights of old stations.	No of intersected points.	No. of triangles.	Error per mile.	No. of heights.					
Mr. J. McGill ...	Cooke and Sons' 7" ...	1,110	37	53	79	″ 9·0	Ft. 0·4	49	10	500	881	Ft. 1·1	280	0·5	0·3	270 (both observers)	537	
„ F. Bell ...	Troughton and Simms' 6"	952	46	57	81	9·0	0·5	44	6	391	673	0·9	109	0·5	0·2		432	

Details of Topography.

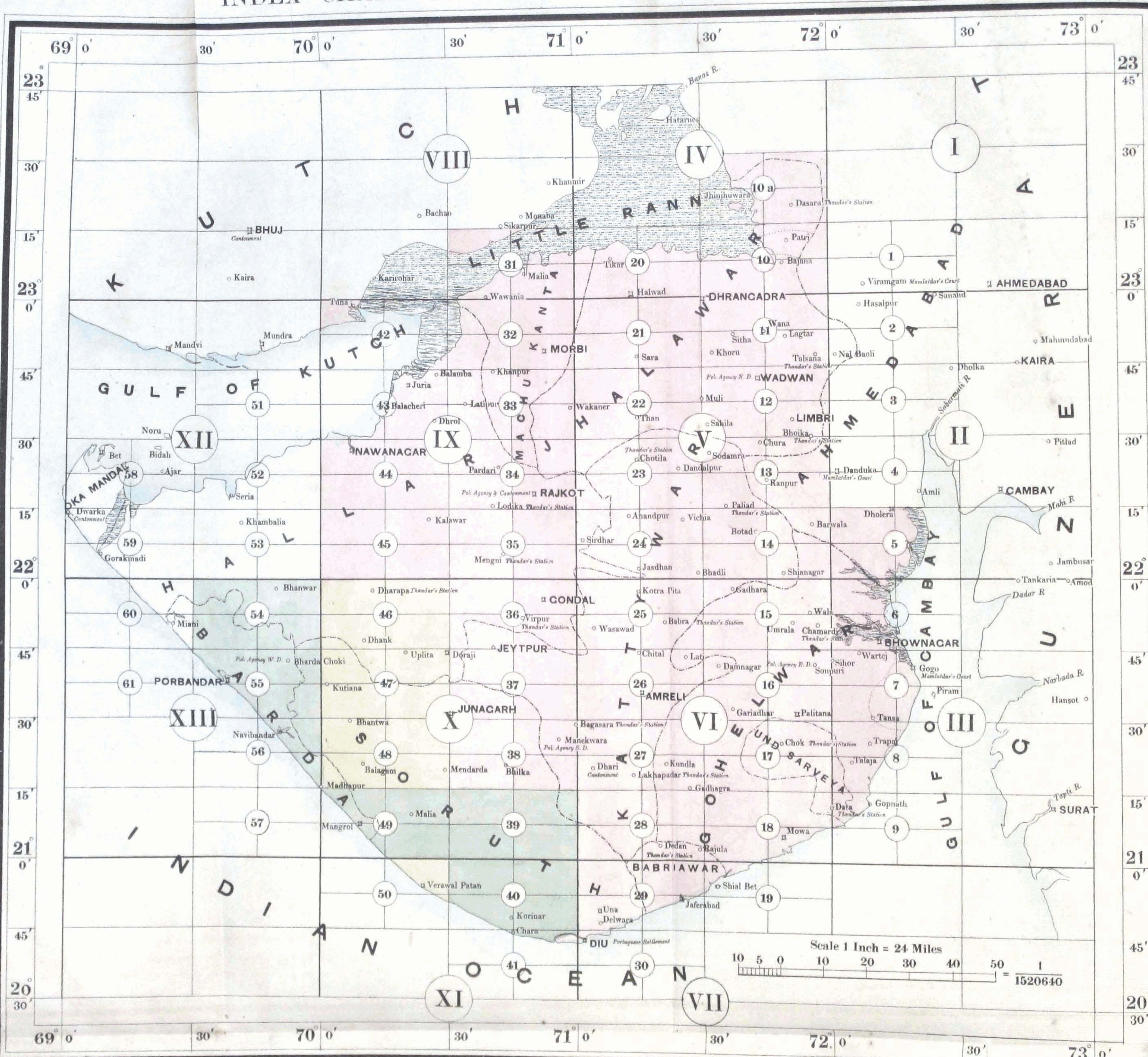
Name.	Area surveyed in square miles.	No. of plane-table stations per square mile.	Remarks.
Major A. Pullan, S.C.	7	9·7	
Mr. N. C. Gwynne	129	6·6	Employed in drawing fair copy of Sheet 38.
„ W. A. Fielding	173	10·4	
„ G. T. Hall	204	9·2	
„ H. Corkery	246	9·4	
„ J. Keating	149	11·4	
Sub-Surveyors.			
Wissaji Raghunath	50	11·6	Also employed in office work at head-quarters' camp.
Narsu Dinkar	86	10·0	
Krishnaji Govind	122	13·4	
Keshu Vital	174	11·4	
Ganesh Ramchandra	209	11·7	
Vishnu Balwant	154	9·4	
Nilkant Vital	13	23·0	
	1,716	11·3	

Details of Traversing.

Name.	Instrument.	Linear miles of traversing.	No of stations.	Average error per 1,000 links.	Average angular error per station.	Lats. and departures.	Remarks.
Narsu Dinkar	5 Inch	85	234	0·9	″ 5·5	2,131 (all four surveyors)	
Krishnaji Govind	Ditto	36	108	1·4	14·9		
Bholnj Bhosekar	Ditto	225	531	0·6	7·9		
Tukaram Chowdri	Ditto	406	1,258	0·7	13·1		
		752	2,131	0·9	10·3		

GREAT TRIGONOMETRICAL SURVEY OF INDIA.

INDEX CHART OF THE **KATTYWAR TOPOGRAPHICAL SURVEY.**



C. DYSON, Photo. C. G. OLLENBACH, Zinco.

The numerals **1, 2, 3** &c., indicate the sheets on the scale of one inch to the mile. The numerals **I, II, III &c.**, indicate the degree sheets, on the Scale of ¼ inch to the mile. The one inch sheets are divided into 4 sections known as the **N. E., N. W., S. E., & S. W.**, sections of the sheet; of these a few copies will be published on the Scale of the original Survey, viz., 2 inches to the mile for the use of local officials.

Denotes country Topographically Surveyed up to 1875-76.
" " " " *in* 1876-77.
" " *Triangulated in advance*
" " *Triangulated and traversed in advance*

Photozincographed at the Office of the Superintendent Great Trigonometrical Survey, Dehra Doon, October 1877.

VII.—Extract from the Narrative Report, dated 7th September 1877, of Lieutenant J. E. Gibbs, R. E., Officiating Assistant Superintendent, 2nd grade, in charge of the Guzerat Party.

Lieut. Col. C. T. Haig., R. E., in charge (until 16th March).
Lieut. J. E. Gibbs, R. E., (in charge from 17th March until 14th June inclusive).

Mr. A. D'Souza.	Lakshuman Ghorpure.*	Virapa Piraji.
„ A. D. L. Christie.	Ganesh Náráyen.*	Rámchandar Vishnu.
„ C. H. McA Fee.†	Ráoji Náráyen.*	
„ J. Hickie.	Bhau Govind.	*Leveling Party.*
*„ G. D. Cusson.	Gannesh Bápuji, 2nd.	Dámodhar Rámchandar.
„ S. F. Norman.	Balwant Govind.	Sitárám Yeshwant.
„ C. A. Norman.	Ganesh Bápuji, 1st.†	
	Mukand Dinkar.†	
Sub-Surveyors.	Govind Gopál.†	*Revenue Survey.*
Mr. H. G. Ferns.*	Monaji Abu.*	Sivaji Nánáji.
„ A. George.*	Balwant Rájárám.	Kubar Parbhudáss.
Gopál Vishnu.	Sáyana Saibu.	Jugal Mánsukhrám.
Bálkrishna Bábáji.*	J. V. DeSouza.*	Parbhu Kisor.

2. The personnel of the Party has been as shown in the margin, and from among them those marked* were employed throughout the field season in the permanent drawing office of the Party, while those marked† were employed partly in field work and partly in the drawing office.

4. Taking Sheet 15 first into consideration, we find in it two towns enjoying municipal self-government.

Sheet 15.

5. The more important one is the city of Surat, in Lat. 21° 11′ N., and Long. 72° 52′ E., having an aggregate population of 107,149 according to the census of 1872. Probably the earliest notice of the place is the mention of its invasion by Persians in A. D. 560. Muhammad Toglak Shah, Emperor of Delhi, sacked the city in 1350, and in 1512 it was discovered and sacked by the Portuguese. The castle was erected about 1542 by Sultán Muhammad Shah, King of Guzerat, as a protection against pirates and faranghis. In 1573, after a brave defence, the city was surrendered to Akbar, the great Moghal Emperor. After this Surat became the chief seaport of the Empire, the storehouse of the riches of India, and the rendezvous of traders from all nations. The first English ship to arrive at Surat was the *Hector*, Captain Hawkins, in August 1608, bearing letters from the Company and from King James I to the Great Moghal, Jahángir, requesting the intercourse of trade. In spite of obstructiveness on the part of the jealous Portuguese, a treaty was drawn up on the 21st October 1612 between Captain. Best and Shaikh Safi, Governor of Ahmedabad, which authorized the establishment of an English factory, and the appointment of an Ambassador at the Moghal Court. This treaty was finally confirmed by an Imperial farmán dated 25th January 1613. The Portuguese struggled long to suppress the English trade, but were worsted in all the important engagements. In 1618 the Dutch obtained a farmán for establishing a factory. The French and Swedes also started factories, but the history of their trade is not brilliant. In 1650 the English factors were imprisoned and had to pay heavily for their release. In 1656 the rival companies in England coalesced, and in 1658 all their factories in India and in Persia were placed under the control of the President and Council of Surat. In 1662 Sir George Oxenden became President, and under him in 1670 the Company's servants gallantly saved the factory and castle from the attack of Sivaji, the great Mahratta Chief, who captured and plundered the city; he had plundered the native town once before in 1664. The defence of the castle was the first engagement between European and Indian troops. In consequence of their generous defence of the property of others, Aurangzeb gave the English further privileges. In 1685 Sir John Child, the President, was ordered to remove his seat to Bombay, where he was soon after appointed Governor General over all the Company's settlements east of the Cape of Good Hope. The English factory now passed through many vicissitudes of fortune, but, on the whole, prospered. In 1748 Moyan-ud-din seized the castle and assumed the title of Nawáb of Surat. On the 4th of March 1759 the English took the castle from the Nawáb, and a dual Government ensued during the reigns of 3 Nawábs, these conducting the civil administration, while the English held the military and naval commands. This arrangement proving very bad, the Company obtained, by treaty on the 15th May 1800, from the Nawáb Nazar-ud-din, whom Mr. Duncan, the Governor of Bombay, had just placed on the "gadi," the entire government of the city and dependencies of Surat. In 1802, by the treaty of Bassein, the Peshwa surrendered his interests in the city and zillah, and by the treaty of Sirji Anjangaon, Sindia surrendered all his claims. In 1842 the last of the direct line of Nawábs of the creation of 1800 died.

Surat.

Surat lies on the left bank of the Tapti, about 13 miles from its mouth, and on the chord of a long bend. The outer wall of the city is about 5½ miles long, and an irregular semicircle in shape, with 12 gates, and some 40 tower-bastions at unequal intervals. There used to be an inner wall about 2¼ miles long. The castle consits of 4 massive round masonry towers, connected by curtains, and a ravelin that was added by the English on the river face. The soil being a treacherous clay of great depth, all buildings suffer, the walls cracking and losing their perpendicularity, and the modern public buildings show that art has not succeeded in overcoming the natural difficulty.

The principal objects of interest are the English and Dutch burial-grounds outside the walls to the north. The old factors seem to have vied with each other in having magnificent tombs erected over their remains; but now many have fallen, and many are almost past repair.

Surat is the chief town of a Collectorate, and possesses a civil and a military station; the latter contains now only one Native Infantry regiment, whereas years ago there were a large force of troops and a naval commodore stationed at Surat. The city has been subjected to several catastrophes. In 1810, 1822, 1835 and 1837 there were great floods causing widespread destruction, and in the last three named years there were also extensive fires. Fires of smaller extent have been frequent. To obviate disasters from floods, Captain Fulljames in 1838 designed and carried out a cut along the chord of the great curve in the river, and, passing to the south of the city, this succeeded for a time in drawing off the superfluous water, but later floods have proved too much for it. Newer municipal works have been more successful in preventing the inundation of the city. The chief want in Surat is good water; almost all the wells are brackish, and among them are many that some years ago were sweet. A large project is in hand which, if carried out, will bring a plentiful supply of pure water for drinking and irrigation from above some rapids near Kamlápur about 35 miles above Surat. The Tapti has shoaled very much since when merchantmen of 500 to 600 tons anchored under the walls of the castle, and the navigation of the river was simple. Now there are a bar and many mud banks off the mouth of the river, and the maritime trade of the city has departed, fishing boats and ferries alone being left.

The present industries at Surat are cotton-ginning and spinning; the manufacture of cotton *saris*; silk weaving and embroidery with china silk; brocade or "kinkháb," paper-making, lacquered work, "Bombay" inlaid box-work, and distilling spirituous liquor from the sap of the Palmyra and date palms.

Rándcr.

6. The other municipal town in Sheet 15 is Ránder, on the right bank of the Tapti, and connected with Surat by the new "Hope" bridge. Its population was 10,280 in 1872. It is one of the oldest cities in southern Guzerat, and after A. D. 1225 became a stronghold of Arab merchants called Náyatás, who expelled the Jáin rulers of the town. It was once the home of many fishermen; now it is of rising importance, containing mills for ginning and spinning cotton, and is the home of a great number of Bohoras and other native merchants.

Dumas.

7. At Dumas on the coast, between the estuaries of the Tapti and the Mindhála, is a small collection of bungalows forming a seaside retreat for the European inhabitants of Surat.

Sachin.

8. Into Sheet 15 comes part of the Sachin State. This estate of seventeen villages was secured to Sidi Abdul Karim, better known as Bálu Mia, by a treaty between the Peshwa and Sir Charles Malet, then Resident at Poona, on the 6th June 1791. Bálu Mia agreed to abide by the terms, which were that he should resign all his hereditary claims to the territory, forts and dependencies of Janjira, and in stead receive the Sachin estate, and abstain from hostile acts against either the Peshwa or the British Government. He afterwards obtained the title of Nawáb of Sachin from the Emperor of Delhi. The Nawábs are by descent Habshis, or Abyssinians. In 1835 all the estate, except two villages, was taken under the management of the British, at the request of the Nawáb, with a view to the liquidation of his debts. The administration of justice is in the hands of the British Government, and the present Nawáb being a minor, the Collector of Surat, as Political Agent, is in charge of the whole estate.

Sheet 15.

9. The Tapti, or, as it should be, Tápi, river forms the southern boundary of the great cotton-growing districts of Guzerat. It is spanned by a fine girder bridge of the B. B. and C. I. Railway at Amroli, and again by the "Hope" girder bridge at Surat. In Sheet 15 are also the estuary and part of the Mindhála river. The country is very flat, and has many arms of salt land, called "khári," overflowed at high spring tides, running in from the rivers between the cultivated areas. The latter bear large clumps of the Palmyra palm (*Borassus flabelliformis*) and the wild date palm (*Phœnix sylvestris*,) which yield enormous quantities of Tári liquor.

Sheets 28, 29 and 30.

10. In the northern portion under survey this year stand the city of Baroda, the town of Dabhoi, and others of minor importance.

Baroda.

11. The city of Baroda, in Latitude 22° 18' N., and Longitude 73° 15' E., is the capital of the territories of the Gáekwár, and lies on the left bank of the Vishwamintri river, a tributary of the Dhádhar.

Baroda, once an ancient stronghold of the Jáinas, was subsequently wrested from them by the Muslim Tartar dynasty of Hindusthán. It was called Chandanavati (city of sandalwood) by Chandan, a Rájput King, one of its conquerors. Afterwards it was named Varavati (abode of warriors.) Priestly influence changed this to Barpatta (leaf of the bar). Hence Baroda, or as the natives write Barodra. The Muhammadan name for the city used to be Daulatábád.

Baroda has belonged to the family of the Gáekwárs since 1732, when it was taken from Abhi Singh, the Mussulmàn governor of Guzerat, by Máhádáji Gáekwár, after the murder at Dákor of his brother Pilaji, the "Sena-Kháss-Kháil," second in command under Dhabáre, the Peshwa's Senápati. Damáji, the eldest surviving son of Pilaji, then came forward, and before long became the most powerful Chief in Guzerat, but having plotted in concert with Tára Bái, Báláji Báji Rao (the Peshwa) treacherously enticed him to his camp and made him prisoner, and only released him in 1753 on the following terms :—equal partition of districts then held by the Gáekwár, and of all future conquests ; 15 lakhs indemnity for past contributions due ; military assistance when necessary ; an annual tribute of 5¼ lakhs ; and certain other minor conditions. From this time dates the Peshwa's permanent supremacy in Guzerat.

During the latter part of the 18th century it was the policy of the British to support the Baroda Government as a counterpoise to the Peshwa. On the 26th January 1780 a treaty of offensive and defensive alliance was signed by Faté Singh Gáekwár and General Goddard, on terms approved by the Supreme Government. At the beginning of this century the finances of the Baroda Government were in an almost hopeless state of confusion and embarrassment, and Major Alexander Walker, who had been appointed Resident, made strenuous efforts to remedy the evil. In 1802 orders were given for the reduction of the military force in Baroda; but the Arab mercenaries revolted, confined Anand Rao Gáekwár, and released Kanháji, the rival claimant of the throne. Serious disturbances in Guzerat being expected, Major Walker called for a European regiment from Bombay in aid of the local subsidiary force, and Colonel Woodington invested the city of Baroda, which was surrendered after an energetic defence for ten days, and the Arabs, after receiving all that was due to them, were forced to quit the country. In return for the assistance from the British, a new treaty was concluded on the 21st April 1805, consolidating previous stipulations and adding others, among which were the increase of the subsidiary force from 2,000 men to 3,000, besides a company of artillery; and the cession of certain districts to the British as well as the Gáekwár's share of the "chauth" of Surat.

The murder at Pandharpur on the 14th July 1815 of Gangádhar Shástri, the agent of the Gáekwár, by Trimbakji, the unscrupulous minister of Báji Rao (the Peshwa), was one of the first of a series of vicious and intriguing acts that led to the dissolution of the kingdom and dynasty of Báji Rao. In November 1817 a treaty was concluded, in which, among other conditions, the Peshwa renounced all rights north of the Narbada, and relinquished all future demands on the Gáekwár. In return for the benefits thus obtained for them by the British Government, the Baroda Darbár assigned more territory to the British as payment for an augmentation of the subsidiary force in Guzerat.

In 1820 the Gáekwár agreed for the future to refrain from interfering with his tributary Chiefs in Guzerat, except through the medium of the British Government.

The subsequent history is of too recent date to be given in a report of this kind. I need only mention that Baroda has been brought prominently into notice lately by the Commission that sat in 1875 to enquire into the attempted murder of Colonel Phayre, the Political Resident, and in consequence of the investigations of which, Malhar Rao Gáekwár was deposed and sent in arrest to Madras.

The present Gáekwár, Sáyaji Rao, being a minor, the administration of the State lies in the hands of the Diwán, Sir T. Mádhava Rao.

Baroda contains a citadel, about 970 by 820 yards, surrounded by a wall having four gates and some 50 bastions, and divided into four square sections by two cross streets. To the south and east are other divisions of the city, which are surrounded by a similar bastioned wall. In the western portion of the city is the old Kothi or Residency. The enclosure, which is surrounded by a wall, is the site of the Jail and the new public offices. The Gáekwár's usual residence is the Moti Bág, and the Diwan's the Mastu Bág, in the suburbs to the S. W. of the town. The old palace is close to the north of the clock tower in the centre of the citadel, and is now used for public offices. Malhar Rao Gáekwár built close to this a magnificent palace, the Nazar Bág, which is of a pure white color, and much ornamented with carvings. In the interior, which is used for Darbárs, there are frescoes executed by a European artist. Malhar Rao had the tower built to such a height as to exceed that of the palace at Makarpura, built by Khande Rao Gáekwár. About ⅓rd of a mile north of the Moti Bág palace is a celebrated well called the Náu Lákhi Báori, and just to the west of the palace is the Máhárája's school, a fine new building, where the young Gáekwár studies, in company with sons of the nobility of the State, under his tutor, Mr. Elliot of the Bombay Civil Service.

There are some fine tanks at Baroda, especially the Sur Ságar in the centre of the town. There is a Hindu bridge over the Vishwamintri, and across a small tributary just beyond there are two bridges, one that was built by Colonel Waddington of the Bombay Engineers, of very elegant design, and the second of native construction, built because the Gáekwár was afraid to cross the other on an elephant, for fear lest the thin-looking crown of the arch should give way. Below the bridge over the Vishwamintri is a bund, which keeps in a large supply of water throughout the hot weather. There is a capital road leading from the city to the cantonment and Residency. This road is raised on an embankment, and yet communication is sometimes interrupted by floods. The Residency is a fine, though very old, house, and stands in large grounds. Opposite is the Rewa Kánta Political Agent's house and office, standing in a capital garden. The cantonment now contains a half battery of artillery, a squadron of cavalry, a detachment of a European and two Native Infantry regiments. The bungalows of the officers are in two rows separated by a broad strip of turf, along which the fine isolated hill of Páwágarh may be seen in the distance. In a central position stands a column erected to the memory of Mr. Williams, once Resident at Baroda, but it bears no inscription. There is an English church that was consecrated by Bishop Heber, a Roman Catholic chapel, and a public garden.

Dabhoi.

12. Dabhoi, situated in Latitude 22° 8' N., and Longitude 73° 28' E., is an ancient fortress, the walls of which form an irregular four-sided figure, approaching to a square. The N., E., S. and W. walls are respectively 1,025, 900, 1,100, and 1,025 yards long, and have a round tower at each angle. The remains of its fortifications, double gates and temples indicate great magnificence. The stones

used are chiefly huge blocks of a very durable sandstone. Of the gates, by far the finest is the Eastern or Hira Gate (Gate of Diamonds). It is covered with handsome carvings representing groups of warriors, animals, birds and serpents. There is a quaint legend about a man having been built up alive in the masonry at the King's orders, but his protectress, the Ráni, used to have him fed by a large quantity of ghi being poured down an opening, which is shown to this day.

Within the walls is a large tank, lined with hewn stone, and having steps all around.

The legend about the building of the city is interesting, and may be found in Forbes' "Oriental Memoirs," Vol. II. It is said to have been built by Siddharája Jayasinha in about A. D. 1100.

Dabhoi was for a long time inhabited by Hindus only, no Mussulmán being permitted to reside within the walls, or to wash in the tank. A young Muhammadan named Sayad Bála, on a pilgrimage with his mother Máma Dukhri, in ignorance of the prohibition, ventured to bathe in the tank, and the Brahmans prevailed on the Rája to mutilate him, and he died. Máma Dukhri at once returned home and sued to her sovereign for redress. He sent a large army under his Vizier, which took Dabhoi after a long siege. The Vizier had all the fortifications destroyed except the western face and the four double gates. When Máma Dukhri died she was revered as a saint, and was buried in a grove near the Hira Gate; by her tomb is a stone of ordeal, and the proof of innocence lies in being able to wriggle through the perforation in the stone.

After this Dabhoi was for many years almost deserted. When the Mussulmáns finally conquered Guzerat, Dabhoi became more populous, and was held by them for two centuries, The Mahrattas then obtained possession of it, and partly rebuilt the walls. During the campaign of 1775 it submitted to Raghoba Peshwa, who levied a contribution of three lákhs, which the inhabitants were scarcely able to pay. In January 1780, General Goddard took the town, on his way to attack Fate Singh Gáekwár, who however gave in and concluded a treaty with the English (see para. 11). Mr. James Forbes, auther of "Oriental Memoirs," was left as Collector of Dabhoi till the 24th April 1783, when the pargana of Dabhoi was with others handed back to the Mahrattas according to treaty.

Dabhoi is now the chief town of one of the Talukas of Baroda territory, and has within the last three years gained in importance by the State Railway joining it with Miágám station of the Bombay, Baroda aud Central India line. It is proposed to connect it also either by tram or railway with Baroda.

Rewá Kánta.

16. In Sheets 28 and 29 are several small estates, under the Pándu Mewás, Rewá Kánta, the most important, being those belonging to the Thákurs of Bhádarwa, Sihora and Cháliar.

Udhad Tenure.

17. In the portion of Kaira under survey are several villages held under a tenure that has not yet been described in these reports, *viz.* Udhad (a Guzerati word signifying "in a lump"). The origin of this tenure dates back as far as the days of Akbar, and it then meant that a village having been carefully measured and an average struck of the value of the produce the land would bear, one-third of this amount was taken as a fixed rental, to be paid without reference to the extent or nature of cultivation, and without any right on the part of the Government to interfere in the internal management, and the whole village community was made jointly responsible for the payment. The oppression exercised subsequently by the Mahrattas partially broke down this system, which received modifications, leading to the present sub-division of "Narwa' and "Bhágwár" tenures.

In "Narwadári" villages (almost confined to Kaira) the lands have never been assessed at rates per beegah; the assessment was fixed in a lump by the Collector, and has in most villages remained unaltered for many years.

In "Bhágwári" villages the lands were assessed at rates per beegah, at the same time as other villages of the district, and their total beegotee assessment forms the lump assessment of the village.

Description of Sheets 28, 29 and 30.

18. With the exception of some patches of open country in the eastern half of Sheet 29, a strip of open country extending along the southern portion of Sheet 28 from near the Mai river, to almost as far as Hálol in the Panch Máháls, and the southern portion of Sheet 30, the country in those Sheets is thickly wooded. In some parts the forest is very dense, the mango being by far the commonest tree, but mixed with the tamarined (especially near village sites), the *mahura* (Bassia latifolia), *kirni* or *rayan* (Mimusop indica), *kawat* (Feronia elephantum, *pilwa* (Salvadora persica), *pipal* (Ficus religiosa), *bar* or *wad* (Ficus indica,) *nim* or *lim* (Mela azadirachta,) and others less common.

The country is also very hedge-bound in parts, especially to the west and south of Baroda, the hedge containing cactus, milk-bush, *arni* (Clerodendron phlomoides) *sitáphal* (Anona) squamosa), *jetimad* (Cadaba indica), kari (Capparis aphylla), and other shrubs of the caper tribe. Close to Baroda there are some hedges of aloes, very difficult to cut through. The suburbs of Baroda are celebrated for the magnificent specimens of tamarind and nim trees to be found there. Here, too, may be seen some very large baobabs, *gorak-amli* (Adansonia digitata), which has been planted at all the ancient seats of Mussulmán power. On approaching Hálol and Kálol in the Panch Máháls many brab, or palmyra palms, are met with.

There are few undulations of surface, except some low hills in sheet 28, and along the banks of the Mahi river. The streams have cut deeply into the soft soil.

The Mewási Rewá Kánta States (Mewás, a fastness) consist of very wild and intricate country, full of deep nalas and jungle-covered ravines, affording great facilities to robbers or outlaws.

The soils are chiefly as follows:—to the right of the Mahi river $\frac{8}{10}$ths is of a light and sandy nature, and the rest approaching to a black loam. South of the Mahi are yellowish sands, loams and clays, till south of Baroda there is blackish loam, very good for rice, containing a large quantity of white sand; then about 6 miles to the south is a slight rise in the country, after which comes black cotton soil varied by loams. In the small portion of the Panch Máháls under survey the soil was chiefly a dark loam.

Rivers.

19. The principal river in the northern area under survey is the Mahi, which traverses Sheets 28 and 29, and forms the eastern boundary of the Kaira Collectorate; the banks of this river are reticulated by deep ravines, especially at the junctions with the Mahi and its tributaries, the Mesri, the Karad and the Mini rivers. The Mahi has cut its way down deeply into the alluvial strata, its steep banks being in places over 100 feet high. The banks contain beds of kankar, which is burnt for lime. The bed is clayey or sandy in most parts, but in the upper half of Sheet 28 the trap crops out all along the bed. In Sheet 30 is the Dhádhar river, with its tributaries the Vishwamintri (on which is situated Baroda) and the Deo; the Vishwamintri again in Sheet 29 has a tributary the Mota Suria. There is also a small tributary of the Dhádhar, *viz.*, the Rangai, which again has a tributary, the Rás; the latter is a peculiar feature, as although at its junction with the Rangai it is only a streamlet with banks about 10 feet deep, it is almost of the same size where it enters Sheet 30, 16 miles to the east, and its course is lined with trees in an otherwise fairly open tract of country.

Lieutenant Gibbs.

22. I was at first employed in triangulating and traversing Sheets 26 and 27 with the assistance of four native Sub-surveyors. I made a net-work of triangles based on the principal stations Ghorarao H. S., Jheria H. S. and Wardhári H. S., extending it until the country became too densely wooded to admit of triangulation without very expensive ray-cutting, but I have succeeded in securing several bases for continuation along the margins of my sheets. I also executed five main traverses. I worked with one of Elliott's 7-inch omnimeters, to test it, but found it to be a very inferior theodolite, the graduations being inaccurate and coarsely done, so that in order to ensure good results I had to repeat oftener than would have been necessary with an ordinarily good instrument.

While triangulating I collected rock-specimens for the purpose of determining the petrology of the district, which is very interesting in the variety of rocks present, and in the thin layer of Deccan trap that reaches Sheet 26; but the results, together with my notes on the botany of the district, can be improved by further observation by the topographers next field season, so that it is best to reserve them for next year's report.

I rejoned head-quarters on the 2nd March, and remained with Colonel Haig till he gave over charge at Surat. Having then re-visited the drawing office at Baroda, I started on a tour of inspection of plane-tables, visiting each of the topographers in succession.

Mr. D'Souza.

23. Mr. D'Souza had charge of the topography of Sheet 15, where he executed the greater part of the northern portion, and besides examined the work in the rest of the sheet. Under him was Bhau Govind, who turned out over 200 square miles of topography in very good style.

Mr. Christie.

24. Mr. Christie was employed first in the preparation of Sheets 6 and 7. As there were a principal series running down the eastern half of the sheets, another along the southern margin of Sheet 7, and a minor series along the western edge of both sheets, Mr. Christie had only to observe 2 triangles, and the rest of the work was all done by main and branch traverses based on the trigonometrical stations. This method was very advantageous; as for triangulation so much ray-cutting would have been necessary that the work would not have been finished in the season.

Mr. Christie was called away on the 14th of February to go to the Dángs. There he executed some minor triangulation and 3 omnimeter traverses in the river beds, working at first with Mr. C. Norman till the latter was thoroughly grounded in the method of working. As usual, Mr. Christie has proved himself to be a very useful assistant.

Mr. McA.Fee.

25. Mr. McA.Fee was at head-quarters with Colonel Haig until my arrival, and was employed in superintending the drawing office in Colonel Haig's absence, supplying lists of data to plane-tablers, and many other duties. When I arrived he was sent to superintend the traversers in Sheets 6, 7, 26 and 27, and besides to complete a little triangulation required in the north-east corner of Sheet 26. He is a conscientious and accurate worker.

Mr. Hickie.

26. Mr. Hickie had charge of the topography of Sheet 29, and was assisted by Balwant Govind and Sáyana Saibu. The western half of the sheet, being very thickly wooded and much intersected with ravines, the work progressed very slowly, and it was necessary to call upon Mr. S. Norman and Govind Gopál to assist in its completion. Mr. Hickie works accurately, his outturn was large,

and he ensured the general accuracy of the whole sheet by constantly changing plane-tables with his natives.

Mr. Cusson.

27. Mr. Cusson had charge of the topography of Sheet 28, having under him Gopál Vishnu and two other native Surveyors. Mr. Cusson's out-turn is good, and Gopál Vishnu worked as usual very well.

Mr. S Norman.

28. Mr. S. Norman had charge of the topography of Sheet 30, except the area done by his brother Under him were 5 native Surveyors. Mr. Norman has become a very good plane-tabler and turns out a large area every year.

Mr. C. Norman.

29. Mr. C. Norman was employed as a plane-tabler in Sheet 30 with Mukand Dinka under him, until he had to go to the Dángs with Mr. Christire. There he surveyed independently 5 omnimeter traverses, and observed rounds of angles at two trigonometrical stations. At the same time, he plane-tabled the banks of the rivers.

Omnimeter traverses.

30. It is very satisfactory to find that the omnimeter traverses in which the distances are determined by the differential subtense readings obtained on a scale by observing to the upper and lower ends of a vertical staff, give far more accurate results than were expected, in spite of the coarseness of the graduations and the inferior make of the instruments. The labour of chaining over the rugged ravines would have been immense; other routes besides the rocky river beds would have necessitated the cutting of the thick undergrowth, and the results are fully as accurate, and probably more so than chaining could have given in such a country. Other advantages of the method are that stations may be selected on prominent points, the traverse crossing from bank to bank wherever convenient, and also that the same observations that give horizontal distances will also yield the relative heights of the stations, thus affording a line of levels. Attached to this report is a copy of a table I have prepared for the distances équivalent to the differences read in the scale.

The portable still.

31. I may as well now mention that Mr. Christie and Mr. Norman report that they had a great deal of sickness among their men, and one of Mr. Christie's khalasis died of jungle-fever. They themselves however, enjoyed capital health, and they both believe that it was mainly due to their having invariably distilled all the water they used for drinking or cooking. An instance in favour of this is that one of their servants, having been frightened into using distilled water by a bad attack of fever at the outset, afterwards remained in good health in spite of his bad beginning. This all bears out the belief in the efficacy of a portable still in unhealthy jungles that I have expressed in two previous reports.

Mr. Ferns.

33. Mr. Ferns, the Head Sub-surveyor, has proved himself very useful. When I was, obliged to be absent from the drawing office for the purpose of inspecting plane-tablers, he kept the office in very good order, and superintended the draftsmen and printers well. He also made all the arrangements for moving the office from Baroda to Dumas in the middle of April. He is himself a first-rate draftsman.

Table of Omnimeter Differentials and Corresponding Distances.

ARGUMENT A. B.=15,000,000.

A	$\frac{100 \times dB}{dA}$	B	A	$\frac{100 \times dB}{dA}$	B	A	$\frac{100 \times dB}{dA}$	B	A	$\frac{100 \times dB}{dA}$	B	A	$\frac{100 \times dB}{dA}$	B	A	$\frac{100 \times dB}{dA}$	B	A	$\frac{100 \times dB}{dA}$	B	A	$\frac{100 \times dB}{dA}$	B
12200	10·0	1229·5	15500	6·2	967·74	19000	4·1	789·47	22500	3·0	666·67	26000	2·2	576·92	29500	1·7	508·47	33000	1·4	454·55	36500	1·1	410·96
3	9·8	1219·5	6	6·1	961·54	1	4·1	785·34	6	2·9	663·72	1	2·2	574·71	6	1·7	506·76	1	1·4	453·17	6	1·1	409·84
4	9·7	1209·7	7	6·0	955·41	2	4·0	781·25	7	2·9	660·79	2	2·2	572·52	7	1·7	505·05	2	1·4	451·81	7	1·1	408·72
5	9·5	1200·0	8	6·0	949·37	3	4·0	777·21	8	2·9	657·90	3	2·2	570·34	8	1·7	503·36	3	1·4	450·45	8	1·1	407·61
6	9·4	1190·5	9	5·9	943·40	4	4·0	773·20	9	2·9	655·02	4	2·1	568·18	9	1·7	501·67	4	1·3	449·10	9	1·1	406·50
7	9·2	1181·1	16000	5·8	937·50	5	3·9	769·23	23000	2·8	652·17	5	2·1	566·04	30000	1·7	500·00	5	1·3	447·76	37000	1·1	405·40
8	9·1	1171·9	1	5·7	931·68	6	3·9	765·31	1	2·8	649·35	6	2·1	563·91	1	1·7	498·34	6	1·3	446·43	1	1·1	404·31
9	9·0	1162·8	2	5·6	925·93	7	3·8	761·42	2	2·8	646·55	7	2·1	561·80	2	1·6	496·69	7	1·3	445·11	2	1·1	403·23
13000	8·8	1153·8	3	5·6	920·25	8	3·8	757·58	3	2·8	643·78	8	2·1	559·70	3	1·6	495·05	8	1·3	443·79	3	1·1	402·14
1	8·6	1145·0	4	5·5	914·63	9	3·8	753·77	4	2·7	641·03	9	2·1	557·62	4	1·6	493·42	9	1·3	442·48	4	1·1	401·07
2	8·6	1136·4	5	5·5	909·10	20000	3·7	750·00	5	2·7	638·30	27000	2·1	555·56	5	1·6	491·80	34000	1·3	441·18	5	1·1	400·00
3	8·4	1127·8	6	5·4	903·61	1	3·7	746·27	6	2·7	635·59	1	2·0	553·50	6	1·6	490·19	1	1·3	439·88	6	1·1	398·94
4	8·3	1119·4	7	5·3	898·20	2	3·7	742·57	7	2·7	632·91	2	2·0	551·47	7	1·6	488·60	2	1·3	438·60	7	1·1	397·88
5	8·2	1111·1	8	5·3	892·86	3	3·6	738·92	8	2·6	630·25	3	2·0	549·45	8	1·6	487·01	3	1·3	437·32	8	1·1	396·83
6	8·0	1102·9	9	5·2	887·57	4	3·6	735·29	9	2·6	627·62	4	2·0	547·45	9	1·6	485·44	4	1·3	436·05	9	1·0	395·78
7	7·9	1094·9	17000	5·1	882·35	5	3·6	731·71	24000	2·6	625·00	5	2·0	545·45	31000	1·6	483·87	5	1·3	434·78	38000	1·0	394·74
8	7·9	1087·0	1	5·1	877·19	6	3·5	728·16	1	2·6	622·41	6	2·0	543·48	1	1·5	482·32	6	1·3	433·53	1	1·0	393·70
9	7·7	1079·1	2	5·0	872·09	7	3·5	724·64	2	2·6	619·83	7	2·0	541·52	2	1·5	480·77	7	1·2	432·28	2	1·0	392·67
14000	7·6	1071·4	3	5·0	867·05	8	3·5	721·15	3	2·5	617·28	8	1·9	539·57	3	1·5	479·23	8	1·2	431·03	3	1·0	391·64
1	7·5	1063·8	4	4·9	862·07	9	3·4	717·70	4	2·5	614·75	9	1·9	537·63	4	1·5	477·71	9	1·2	429·80	4	1·0	390·62
2	7·3	1056·3	5	4·9	857·14	21000	3·4	714·29	5	2·5	612·24	28000	1·9	535·71	5	1·5	476·19	35000	1·2	428·57	5	1·0	389·61
3	7·3	1049·0	6	4·8	852·27	1	3·4	710·90	6	2·5	609·76	1	1·9	533·81	6	1·5	474·68	1	1·2	427·35	6	1·0	388·60
4	7·2	1041·7	7	4·8	847·46	2	3·3	707·55	7	2·5	607·29	2	1·9	531·91	7	1·5	473·19	2	1·2	426·14	7	1·0	387·60
5	7·1	1034·5	8	4·7	842·70	3	3·3	704·23	8	2·4	604·84	3	1·9	530·04	8	1·5	471·70	3	1·2	424·93	8	1·0	386·60
6	7·0	1027·4	9	4·7	837·99	4	3·3	700·93	9	2·4	602·41	4	1·9	528·17	9	1·5	470·22	4	1·2	423·73	9	1·0	385·60
7	6·9	1020·4	18000	4·6	833·33	5	3·2	697·67	25000	2·4	600·00	5	1·8	526·32	32000	1·5	468·75	5	1·2	422·54	39000	1·0	384·62
8	6·8	1013·5	1	4·6	828·73	6	3·2	694·44	1	2·4	597·61	6	1·8	524·48	1	1·5	467·29	6	1·2	421·35			
9	6·7	1006·7	2	4·5	824·18	7	3·2	691·24	2	2·4	595·24	7	1·8	522·65	2	1·4	465·84	7	1·2	420·17			
15000	6·6	1000·0	3	4·5	819·67	8	3·1	688·07	3	2·3	592·89	8	1·8	520·83	3	1·4	464·40	8	1·2	419·00			
1	6·5	993·38	4	4·4	815·22	9	3·1	684·93	4	2·3	590·55	9	1·8	519·03	4	1·4	462·96	9	1·2	417·83			
2	6·5	986·84	5	4·4	810·81	22000	3·1	681·82	5	2·3	588·24	29000	1·8	517·24	5	1·4	461·54	36000	1·2	416·67			
3	6·4	980·39	6	4·3	806·45	1	3·1	678·73	6	2·3	585·94	1	1·8	515·46	6	1·4	460·12	1	1·2	415·51			
4	6·3	974·03	7	4·3	802·14	2	3·0	675·68	7	2·3	583·66	2	1·8	513·70	7	1·4	458·72	2	1·1	414·36			
			8	4·2	797·87	3	3·0	672·65	8	2·3	581·40	3	1·8	511·95	8	1·4	457·32	3	1·1	413·22			
			9	4·2	793·65	4	3·0	669·64	9	2·2	579·15	4	1·7	510·20	9	1·4	455·93	4	1·1	412·09			

Remarks.

Examples.

Differential = δ measurement on scale.
Distance = D

(1.)
δ = 15643
(A) = 15600.........(B) 961·54
·43 × − 6·1 = − 2·62
D = 958·98
or 959 links or feet.

(2).
δ = 9580
(B) = 96154.........(A) 1560·0
26·4 ÷ 6·1 = + 4·3
D = 1564·3
or 1564 links or feet.

Either A or B being taken to represent the scale measurement, the other gives the corresponding horizontal distance.
The column of differences should be headed $\frac{100 \times d\,B}{d\,A}$.

TABULAR STATEMENT OF WORK EXECUTED BY THE GUZERAT PARTY DURING THE FIELD SEASON 1876-77.

Details of Triangulation.

Observer's Name.	Instrument.	Area prepared for Topography by triangulation & traversing.	No. of Stations visited.	3 Angles observed.				2 Angles observed.				Average No. of trigonometrical and traverse points per square mile.	Average No. of heights per square mile.	Remarks.
				No. of triangles.	Triangular error.	Error per mile in inches.	No. of heights.	No. of Intersected points.	No. of triangles.	Error per mile in inches.	No. of heights.			
					In.									
Lieutenant J. E. Gibbs, R.E. ...	Omnimeter ...	2,200*a*	89	60	8·0	2·1*d*	35	95	? 175	3·3 *g*	6	Exclusive of traverse intersected points = 2·02	Including trgl. heights and existing levels of the B. B. and C. I. Railway, the Bo. T. and Lg. Party and the Irrigation Department, there will be an ample number.	*a.* Total area prepared for topography, exclusive of Dangs, *see* paragraph 3 of Lieutenant Gibbs' report.
Mr. C. H. McA. Fee ...	6-inch Theodolite by T. and S.		10	10	14·4	1·1*e*	5	5	8	20·5 *h*				*b.* Total area in Dangs ready for topography on 4-inch scale.
„ A. Christie ...	6-inch Theodolite by T. and S.		4	2										*c.* One of these fixed only by interpolation.
„ do. ...	Omnimeter ...	280*b*	34	40	11·5	3·6*f*	30	56	132	22·6 *k*	2			*d.* Average of 37 common sides.
Mr. C. A. Norman ...	Omnimeter ...		2*c*											*e.* „ 4 „ *f.* „ 7 „ *g.* „ 60 „ *h.* „ 1 „ *k.* „ 28 „
Total ...	......	2,480	89	112	...	...	70	156	...	...	8			

Details of Topography.

Name.	Area surveyed in square miles.	No of plane-table stations per square mile.	Remarks.
Mr. A. D'Souza ...	156·72	13·8	Besides examination of Bhan G's work.
„ J. Hickle	205·63	11·8	Besides examination of Balwant G.'s and Sayana S.'s work.
„ G. D. Cusson ...	174·93	9·3	Besides examination of Gopál V.'s, Ganesh B.'s, and Balwant R.'s work.
„ S. F. Norman ...	242·86	7·1	Besides examination of Raoji N.'s, Mukand D.'s, Govind G.'s, and Virapa P.'s work.
„ C. A. Norman ...	124·79	9·9	
Gopál Vishnu	200·49	12·1	
Bhan Govind	201·75	15·4	
Balwant Govind ...	134·90	21·1	
Ganesh Bápuji, 1st ...	29·79	25·0	
Mukand Diokar ...	61·00	14·0	
Govind Gopál	36·56	17·3	
Balwant Rájarám ...	159·84	11·7	
Sáyana Saibu	168·84	17·4	
Virapa Piraji	18·95	18·6	
Raoji Nárayen	105·17	16·1	
Total and Average ...	2019·22	15·0	
D D Overlap ...	31·44		
Total ...	1987·78	Within graticule.	

Details of Traversing.

Name.	Instrument.	Linear miles of traversing.	Average error per 1,000 links.	Average angular error per station.	Remarks.
				In.	
Lieutenant J. E. Gibbs, R.E. ...	Omnimeter ...	59·81*a*	0·61	9·0	*a.* Main traverses which have been computed in "systems," so as to harmonize—one traverse by Sitaram Yeshwant having been included in a "system."
Mr. A. Christie	6-inch Theodolite by T. and S.	137·77*a* 15·50*b*	0·67	12·3	
	Omnimeter ...	19·04*c*	0·84	4·9	
„ C. A. Norman	Omnimeter ...	56·41*c*	4·79	14·7	*b.* Baroda State boundary traverses.
Ganesh Bápuji, 2nd ...	5-inch and 6-inch Theodolites by Cook and Sons.	42·07 229·14*b*	1·66	18·3	*c.* Omnimeter traverses, *i. e.*, those in which the distances between stations were obtained by subtenses instrumentally.
Ganesh Bápaji, 1st ...		3·99 44·02*b*	1·11	12·4	
Rámchandar Vishnu ...		97·96 84·25*b*	1·26	14·1	*d.* Besides three traverses that would not close—
Shivrám Nárayen		13·82*d*	0·13	20·7	Total number of traverse stations fixed this year— In sheets 26, 27, 6 and 7 ... ... 4,206 In sheet 52 (Dangs) ... ... 461 In published sheets (boundary traverses) ... 1,374 Total ... 6,041
(*Leveling Party.*)					
Dámodhar Rámchandar ...		23·24 21·89*b*	2·78	7·0	
Sitarám Yeshwant		8·33*a* 71·33 124·95*b*	1·70	16·3	
(*Revenue Survey*)					
Sivaji Nánáji		170·17 76·07*b*	0·92	17·8	
Kubar Parbhudáss ...		170·85 5·79*b*	1·27	22·0	
Jugal Mánsukhrám ...		255·74	0·62	10·8	
Parbhu Kisor		217·55 14·89*b*	0·64	16·2	
Total ...	......	1348·09 616·50*b*			
Grand Total ...	......	[illegible] miles.			

GREAT ... METRICAL SURVEY OF INDIA

29_a

INDEX CHART OF THE GUZERAT TOPOGRAPHICAL SURVEY

The numerals 1, 2, 3 &c., indicate the sheets on the scale of ... inch to the mile

Extract from the Narrative Report, dated November 28th, 1877, of E. C. Ryall, Esq., in charge Kumaon and Garhwal Party.

3. On the 9th March my camp left Dehra Dún for Almorah; I myself followed on the 14th by dák and rail, with a view to completing my preparations at that station. It was my intention to move up the party from Almorah as early as possible, so that I might be enabled to accomplish the survey before the setting in of the rains. On the 25th March the whole party was got together at Almorah, and by the 1st April it was fully equipped for its northward journey. Owing, however, to heavy rains, I did not find it expedient to push on till the 10th April. On that day Mr. J. Peyton left for the Byans Valley, which lies to the north-east of Kumaon, bordering on Nepal. Messrs. Pocock and Warwick left on the same day for the Dharma Valley, lying contiguously to the west of the Byans Valley; I myself, together with two Native Sub-Surveyors, marched for the Upper Jowar Valley on the 14th.

4. About four days after my departure from Almorah, clouds and rain again troubled us. At Bageswar, my second march out of Almorah, I received intimation that Mr. Warwick had fallen ill; I therefore directed him to join my camp for medical treatment, which he did on the following day. This circumstance at the time gave me no little cause for anxiety; however, all went fairly well with him afterwards, though he was ailing more or less throughout the season.

5. The winter of 1876-77 proved to be the severest known for many years past amongst these hills; the spring was wet and cold, and felt quite wintry. When I left your head-quarters, Dehra Dún, I was in hopes that the wet weather would not last long; it continued, however, with few intermissions till the 8th June, the most noticeable break-up to that time being from the 9th April up to the 17th. After the 8th June, there occurred but few falls of snow on the higher mountains, the heaviest being between the 2nd and 4th of July, when the passes leading into Thibet became almost impracticable.

6. Mountains which in ordinary years had their snow line at the end of April at an elevation of 12,000 feet above sea level, were mantled with snow down to 9,000 feet, and valleys, which at that time of year used to be clear of snow up to 10,000 feet, were literally choked with snow down to 6,000 feet, this accumulation in the valleys being caused by snow drifts and avalanches from the mountain sides.

7. Consequent on the prolonged wet weather, the inhabitants of the upper valleys found it impossible to make for their summer homes till very late in the season; the usual time for their migration northwards being about the end of April. So, when the Survey Parties were marching for their ground, they met these people, from whom alone they could expect assistance, camped about the lower valleys. This state of things made matters look very inauspicious. I had great fears lest the monsoons should come down upon us before the people could be induced to move up.

8. My assistants had rather difficult people to deal with in the Bhoteas of Dharma and Byans. They made frequent efforts to induce these people to move, and only succeeded after considerable delay just in time. My case, however, was seemingly worse. On my line of march I met the inhabitants of the Upper Jowar or Milam Valley loitering about the banks of the Sarju and Ramganga. These people possess an advantage over those of the other Bhot Pergunnahs of Kumaon and Garhwal, for they own intermediate homes in Munshiári, a district lying at the foot of the Milam Valley. Here numerous villages belong to them, and extensive fields are cultivated for them by Hindu tillers, permanent residents of the place. These villages being on an average not over 6,000 feet, the inclemency of the weather could not have kept them away. The cause I ascertained to be the raging at Munshiári of an epidemic, locally known as "mahamari" or "gola," which had carried off many of the Hindu inhabitants of these localities; but at the time I got there, 20th April, the disease had greatly abated. Nevertheless, the villages were entirely deserted by their Bhotea inhabitants.

9. As I had allotted to myself a large share of the topographical work, as well as the extension up to the frontier of Thibet of a series of triangles, I could not afford to lose much time, and it became clear to me that I must push through in spite of the ill-conditioned state of the valleys and passes on ahead. I accordingly summoned the influential men amongst the Bhoteas, whom I met along the Sarju and Ramganga, and they readily obeyed my call. They promised to take their people up to the Milam if I would show them the way; but under any circumstances they said they could not make a move for at least another twenty days. Meanwhile I undertook to clear the way.

10. In anticipation of meeting with some road-cutting difficulty, I engaged at Almorah nine professional road-cutters; these were, however, far too small a number for the heavy work before them, so I engaged sixteen other men from amongst the Hindus of Munshiári. On the 23rd these men began their work, and by the 29th they had made sufficient progress to enable me to move on. After collecting supplies for establishment and coolies, I commenced my journey northwards, and on the 6th May my detachment succeeded in getting into Milam village, catching up the road-cutters within a few miles of that place. There are in all twelve villages in the Milam Valley, and I found most of the houses in them burried in snow. The journey up was harassing, aggravated by falls of rain, sleet and snow. Except in those parts of the valley which were open, and consequently more exposed to the influence of the sun, I found it difficult to get a spot for pitching the camp on without clearing off the snow. At Milam itself, after my arrival there, it snowed for about eight days with but some occasional

breaks lasting for a few hours each day. I had a mistaken impression at the that once over the Unta Dhurra Pass, the greater portion of my snow difficulties would be at an end, and I directed that the road-cutting establishment should press forward and make efforts to clear that Pass. They failed twice, the recent falls of snow greatly crippling their moements; at the third attempt they succeeded in getting over. They were at this work for more than a fortnight. In the meanwhile I carried on the topography of the Milam Valley as far as that was practicable.

11. On hearing of the opening of the Unta Dhurra Pass, 17,350 feet above sea level, I arranged to get across; and on the 30th May I resumed my march upwards. Though only about 13 miles away, I did not succeed in crossing the Pass till the fourth day. Now were left before me two more Passes, not quite so formidable as the first, but very trying notwithstanding.

12. On the 8th June I succeeded in getting into Hundes, as that portion of Chinese Thibet lying to the north of Kumaon and the two Garhwals is called. I was much disappointed, however, at being greeted on the southern face of the Balchdhurra Pass, leading into Thibet, by two Hunias.

13. To go on with instruments, I was bound to give some plausible reason; so I explained to the two Hunias, who were about to return at once to Daba, that my object was to survey the northern limits of British territory, which I found impossible to do from the southern faces. Before their departure I made them quite happy with gifts of rice, ata, &c.; one of them turned back carrying my message to the Daba Jongpan, as the Ruler of these parts is called, and the other followed me the next day accross the Pass. Two days after this, I reached and observed at my first station, Chilamkurkur hill-station. On my return from this station I was met by ten or twelve other Hunias, despatched to my camp by the Jongpan. They brought me a message conveying a mild reproof at my entering into the district, but added that as I had come, I was at liberty to go on with what I was doing, on the condition, to which I readily agreed, that I should not cross the Sutlej. These men stayed with my camp several days, helping in pitching my tent and bringing in supplies of fuel. In time others from distant grazing grounds brought in sheep, milk and butter for sale. My escort of a dozen then gradually dwindled down to four; these again left me on the 2nd July, when I re-crossed the Balchdhurra Pass into British territory.

14. I was in all about twenty-four days in Hundes, during which time I succeeded in observing at sixteen stations, from which I took angles to about 45 distant peaks, whose distances average about 60 miles; about thirty other peaks were also observed to at an average distance of about 30 miles. About half the number of points have vertical angles observed to them.

15. After doing all I could in Hundes, I hastened back to form a connection between the work there and the base on the Unta Dhurra ridge. As I had succeeded in laying down points which circumscribe a very large area of country, roughly estimated at about 13,000 square miles, I thought it would be as well to double the series running up the Unta Dhurra gorge, the sides there being necessarily very short, and some of the angles rather acute. I, accordingly, on my return towards Milam, undertook this work, and by the 25th July accomplished it.

16. In 1874, while triangulating up the Milam Valley, I was unable, owing to heavy rains and other causes, to observe the third angles at some of my stations. These were six in number; including these, the total number of points visited during the season is 27; the average height of them is about 17,800 feet, the highest being a little short of 19,600 feet.

18. When I returned from my triangulation, I finished the topography of the Milam valley. I also topographically surveyed the eastern range of the northern valleys, making at the same time a reconnoissance of about 70 square miles in Hundes. The interior details of the northern valleys were filled in by my native Sub-surveyors. The area of topographical work done by me is 640 square miles, which includes 120 square miles of reconnoissance in Hundes,

19. The length of the series carried up by me is about 52 miles, and the area triangulated, exclusive of that embraced by distant points, is about 560 square miles.

20. On the 4th August I left the Milam valley for Almorah, where I arrived on the 15th, shortly after which Messrs. Peyton and Warwick joined me.

Mr. Pocock came in about the end of August, and the native Surveyors about the 20th September.

21. I shall now proceed to report on the work of my Assistants. I have in some of the foregoing paragraphs touched upon a few difficulties which were common to every member of the Party, so they need not be recapitulated here.

22. Mr. Peyton being my most experienced hand, I directed him to take up the survey of the Byans valley which had not in it a sufficient number of trigonometrically-fixed points to make it safe to give it up to a less experienced Surveyor. Moreover, I supplied him with a 7" theodolite, so that he might lay down some points in the north-east corner of the Byans valley should he find it necessary to do so. He was further instructed to obtain, if possible, some bases on the frontier, with a view to laying down some trans-frontier points from them. Mr. Peyton, while carrying on a series of triangles up the Byans valley, succeeded in laying down numerous points in it; but he found it impossible to obtain any base on the ridge which overlooks the trans-frontier country. The triangulation executed by him extends over an area

of 310 square miles; his topographical work amounts to 502 square miles, executed on the scale of half an inch to a mile, including 67 square miles of reconnoissance. I consider Mr. Peyton to have turned out an excellent field season's work

23. I beg to submit here some notes by Mr. Peyton on his work, and the topography of the Byans Valley:—

"The weather last winter was exceptionally severe throughout the northern districts of Kumaon. Hills rising to only 12,000 feet were perfectly white to about two-thirds of the distance from the summit to the base. The quantity of snow on the mountains, which was continually increasing, held out a dismal promise for my chance of surveying the higher regions, and caused sufficient delay to disarrange my plans to enter Byans at an early part of the summer. The passes across the watershed between Byans and Thibet, which are generally open about the first week in May, were inaccessible to travellers from the south till a much later period; for I met the first batch of traders from Kumaon proceeding to Taklakot about the middle of June, and even then many portions of the high road to Thibet were blocked with snow; the drifts were deep, and a few days later, when I was approaching the Lipu Lek pass, all trace of the path was obliterated. This long continued spell of bad weather all through the summer is in these hills highly exceptional.

"My camp reached the Nirpania pass (11,257 feet) leading into Byans on the 25th May, and here I halted for a week, anxiously looking out for a break in the weather, for snow was still falling, and towards the higher of the two Nirpania stations it lay very deep. This is the only route up the Byans Valley, all communication with which is cut off in winter, when much snow lies on the Nirpania range; and drifts on the road side 25 feet deep are said to be common.

"In June there were only eight clear days, when I got good views of the mountain peaks far and near. On the 3rd July, when I was in the Kuti Valley, there was a snow-storm accompanied by a cold raw wind, which repeatedly veered round the compass. The entire valley, for six days after the snow fell, was perfectly white down to the rocks on the river. In July I had only five days of clear blue sky, when the mountain features generally blurred by fog and mist, were distinctly visible. I was greatly surprised to find that, in the Kuti Valley, where I was fairly behind most of the great snow and rain-collecting mountains, there was no change in the climate; the weather was seldom fine for more than a couple of hours in the morning, and I rarely returned dry to my tent from an excursion to any of the mountains above 12,000 or 13,000 feet.

"As soon as the passes into Thibet are open, there is considerable traffic on the main road through Byans, and several parties of Thibetian traders travel down to Kumaon with flocks of sheep laden with salt and borax. At a much earler period, or as soon as the snow disappears from elevations below 11,000 feet, the Bhoteas return from their winter trip to the lower hills, and proceed to their villages in Byans.

"I made inquiries regarding my ability to penetrate farther than our territory, as far at least as Taklakot, which is a place of some importance, lying on the trade route between Kumaon and Thibet; and all I learnt was discouraging and against my chance of going there. I made the Taklakot officials presents of brandy, goats, and cloth, and they accompanied me as far as the pass, but nothing would induce them to concede the point relative to the extension of my journey to Taklakot.

"There is a very rough road on the northern side of the pass of Nirpania leading into Byans, very rocky and difficult,—a staircase, as it may properly be called, overhanging through its whole extent a series of frightful precipices, nearly perpendicular, where fatal accidents have often taken place, which the guides never fail to relate with every appalling circumstance. It gets worse as you descend to the valley, and being quite unprotected as it leads along bluff faces of cliffs by rocky steps and rotten planks, the sense of insecurity is very great. The mountains here are intersected by a network of narrow valleys, the opposite faces of which approach each other so closely at some points, that it is possible to shoot an animal, or even throw a stone across the gorge.

"The Byans Valley communicates with Thibet by three routes, the principal and earliest open to travellers is called the Lipu Lek pass. The extent of snow which the traveller will encounter depends entirely on the season; it varies from two to seven or eight miles, but in moderate weather this is a very easy pass indeed; on the 21st June we had a bright morning after a cold night at the foot of the pass, where the camp was pitched on a narrow plain, 15,000 feet above the sea; making an early start, we followed a valley to the south-east, the path lying over beds of recent snow; a little after sunrise when we were not far from the summit a cold wind was blowing, which made the cold already intense, almost unbearable; for the iciness of a Thibetian breeze, especially at these elevations, is something which only those who have experienced it can imagine. I was moreover ascending the pass on its shady side, and so, until I reached the top, was deprived of any warmth to be got from the sun's rays. From the pass there is a fine view of the Thibetian hills, framed as it were by the vast shoulders of the snowy range. For a short while the mist rising from the valleys had nearly blotted out the lower landscape, but the white, and in some places purple, outline of Nammu Nanghil (Anglice: youngest sister of the king of Heaven, 25,200 feet) was sharp against a clear sky; the plain beneath looking very faint till the sun beat on it, when it appeared of a reddish colour, without a tree or a speck of green anywhere. The main chain of the frontier reaches its greatest elevation and true central point in the mountain mass (22,000 feet) which towers over its off-shoots above the sources of the Kuti river. The southern spurs of this range descend to the main valley in long-serrated ridges, marked by cones, needles, and spires, which shoot up into the sky even higher than the northern peaks, and terminate abruptly in a line of precipices and crags which skirt the river.

"The highest mountain on the east watershed of the Kali is Nampa (23,350 feet), with steep snow beds cut into vertical ridges, and great towers of rock shooting out from below, between which are several extensive glaciers. With the exception of these glaciers, and that of Mang Shang, east of the Lampia Lek pass, there are very few of any size on the southern side of the main range. The Mang Shang glacier descends from the snow plains between two beautifully white mountains in a magnificent sheet, remarkably uniform and yet very steep. On the Dharma side the largest glacier, called 'Sumzunkchan Kagal,' is about seven miles in length, and occupies a considerable portion of the lateral valleys south of the village of Kuti.

"There are seven villages in Byans, all *fac similes* of each other: Garbia probably the largest, with a population of 500. With the exception of some half a dozen houses, built in the style of a Swiss Chalet, they are all low and small, the building materials being for the most part furnished by the cedars that cover the Shialek range south of Garbia. The village stands on the right bank of the Kali, opposite the valley formed by the Tinkar stream which comes from Nepal, the ground in some places being covered with accumulations of alluvium and in others cut into cliffs by the river. The great characteristic is sterility; hill and valley, on the whole, presenting an expanse of stony waste. The northern ranges average from 16,000 to 22,000 feet, the valleys being 9,000 to 12,000 in the agricultural, and 11,000 to 14,000 in the pastoral districts. The main valley through which the Kuti, the larger of the two streams which traverse the district, flows, at its broadest part scarcely widens to more than one hundred yards, and is shut in by the towering peaks that run north and south respectively to Hundes and Dharma. The total length of the valley is 31 miles, and the highest peaks to the north have an elevation of more than 22,000 feet.

"The Bhoteas in these high regions are a sturdy race of hillmen, with no caste prejudices, for they will eat game of all kinds, and drink to any extent. They are principally engaged in agriculture, and breeding sheep and goats; all their clothing is made by hand looms, the wool procured from their own sheep. At all the villages I visited, the women seemed industrious and happy; their staple trade is the weaving of woolen blankets, or plaids of bright colours. They also make fancy scarfs for the waist and other small articles of the kind; and occasionally act as coolies when there is a lack of men. At Garbia the Tartar physiognomy is by no means predominant, and although the noses are generally somewhat broad and the cheek bones large and prominent, yet I saw some faces which in any country would be acknowledged to be pretty and expressive. I found the men always faithful to their engagements, and many of them in their attendance on my camp went through great hardships and inconveniences, roughing it on high mountain tops without shelter of any kind, exposed to sleet and snow, and often to a cold cutting wind."

24. Mr. Pocock, who succeeded so well on a former occasion in accomplishing the survey of the Mana Valley,—a very lofty region towards the north-west of British Garhwal,—was deputed by me to take up the northern portion of the Dharma Valley, which appeared to me from all accounts to be equally lofty and far more craggy. He was not able to begin work till the first week in June; the enormous quantities of snow he had to go over considerably retarded his progress, but by the 15th August he contrived to finish his work. He was only employed in topography on the scale of half an inch to a mile, and his out-turn is 294 square miles. As the Byans Valley lies contiguous to the Dharma, the difficulties met with by Mr. Pocock, arising from inclemency of weather were similar to those encountered by Mr. Peyton; perhaps more aggravated, owing to the greater altitude he had to work in. The highest plane-table station of Mr. Pocock is about 19,000 feet, average about 16,500 feet.

25. To Mr. Warwick I allotted the southern portion of the Dharma Valley. He also experienced the vicissitudes of weather complained of by Mr. Peyton, but as he was not employed in very lofty ground, he felt them to a lesser degree. Mr. Warwick, as I have stated, fell ill at the very out-set: he was more than 20 days ill, but recovered sufficiently at the end of that time to march off to his ground. He suffered more or less throughout the season, but managed with perseverance to get through his share of the work, which amounts to 163 square miles of topography on the half-inch scale.

27. The entrance into the Milam Valley is through a stupendous gorge, overhung by large masses of granite precipices; this gorge is about 12 miles in length, and the road through it is for the most part a mere series of narrow steps built along the faces of steep hill sides or rugged precipices, and where this is impracticable, planks leading from one ledge of a precipice to another are laid across. After the first 12 miles the country becomes more open. The mountains here are composed of three different kinds of rock; the lowest formation is granite, of which all the most lofty peaks are composed; the second is a hard slate; and the third and highest is a hard crystallized limestone. The mountains are not very precipitous near the sides of this portion of the valley. The open part of the Milam Valley is about 14 miles, up to the village of Milam. Here the valley splits up into two; the one to the west is occupied by an extensive glacier running down to within two miles of the village; the other might be called a narrow gorge extending up to the very watershed line on the Unta Dhurra. The formations in these two valleys are the same as those found in the open parts of the valley below. At the foot of the Unta Dhurra range lies a glacier about 4 miles in length, and owing to this glacier the approach to the pass is extremely difficult. The Unta Dhurra pass is the most difficult of all the passes in Kumaon and Garhwal.

28. The two northern valleys, owing to the absence of a general name for them, might be called the Girthi and Kiangur valleys. The drainage of these valleys falls into the Dhauli river in the Niti valley. The Girthi valley is bounded on the north by sheer cliffs of limestone rising to over 19,000 feet; on the south it is belted by peaks and ranges averaging over 21,000 feet. The highest parts are composed, to all appearances, of granite, and the lower of limestone in a semi-crystallised state. The Kiangur valley is entirely composed of this limestone; its southern slopes are precipitous, but the northern slopes, though lofty, are for the most part undulating, and present a view for 15 miles of pleasing softness when compared with the ruggedness of the southern ridges. These slopes are richly covered with verdure up to about 15,000 feet, and at their bases a description of furze is found to grow luxuriantly, the roots of which make capital fuel. At the time of my passage through, the entire valley was covered with snow; and it was only on my return from Hundes in July that I was greeted with all the bloom of spring, though it was past midsummer.

30. Before concluding this, I would beg to bring prominently to your notice the services rendered by Dhannu, Jangpani of the village of Burphu in the Milam Valley, and of Rapti in Munshiari. On previous occasions Dhannu has rendered very good service as head manager of the camp, in procuring supplies and rendering himself generally useful. This year it was chiefly due to him that I was able without much trouble to make the extensive preparations which were necessary for conducting supplies, first over five marches in the Milam Valley, and then over eleven marches of sterile and barren country.

He is a man possessing extensive influence and tact.

32. During the conduct of the field operations in Kumaon and Garhwal, Mr. W. Todd was left in charge of the mapping department of my office. Of the Dehra Dún Survey on the scale of four inches to the mile, the following maps have been completed, *viz.*, Nos. XXIII, XXX, XXXIII, XXXIV, and XL; of the remaining sheets of the same survey, Nos. XXIV, XXXI, XXXII, XXXVIII and XXXIX require typing of names to complete them for photozincography. The drawing office helped in outlining sheets XXIV and XXXII, and in both outlining and shading sheet XL.

33. The outlining of the four sheets of the Jaunsar Báwar Survey, on the scale of two inches to the mile, has been done, with the exception of those portions surveyed by the Forest Department.

34. The two sheets of the large scale map of Dehra and its suburbs (twelve inches to the mile) have been outlined.

35. The reduction of the Dehra Dún maps from the scale of four inches to a mile to that of one inch to a mile is in progress.

36. *Pari passu* with the supervision exercised by Mr. Todd in the mapping work, he was employed for about a month in drawing up a narrative of the Mullah's explorations.

Mr. Kinney joined the office about the middle of May, and rendered Mr. Todd great assistance by taking up the shading of six and a half sheets of the large scale, Dehra Dún Survey. The progress made in the drawing work is very creditable to Messrs. Todd and Kinney.

KUMAON AND GARHWAL SURVEY,

Tabular Statement of out-turn of work, season 1877.

Details of Triangulation.

OBSERVER'S NAMES.	Area of triangles in square miles.	Number of stations visited.	Number of triangles of which all three angles have been observed.	Number of intersected points fixed.	Number of points whose heights have been determined.	Average altitude in feet above sea-level of stations visited.	REMARKS.
E. C. Ryall, Esq. ...	560	27	26	75	57	17,800	Exclusive of 13,000 square miles embraced by intersected distant, snowy peaks in Thibet. Length of series of triangulation = 52 miles.
Mr. J. Peyton, ...	310	12	9	21	26	13,090	The series of triangulation executed = 18 miles in length.
TOTALS ...	870	39	35	96	83	...	

Details of Topography, Scale, 1 inch=1 mile.

NAME.	Area surveyed in square miles.	Average number of plane-table stations per square mile.	IN FEET ABOVE SEA-LEVEL.			Area of glaciers in square miles.	REMARKS.
			Average height of ground surveyed.	Average height of plane-table stations.	Maximum height of points visited.		
E. C. Ryall, Esq. ...	640	0·32	19,000	15,000	19,600	33	Includes 120 square miles of reconnoissance.
TOTALS ...	640	0·32	19,000	15,000	19,600	33	

Scale 1 inch=2 miles.

NAMES.	Area surveyed in square miles.	Average number of plane-table stations per square mile.	IN FEET ABOVE SEA LEVEL.			Area of glaciers in square miles.	REMARKS.
			Average height of ground surveyed.	Average height of plane-table stations.	Maximum height of points visited.		
Mr. J. Peyton, ...	350	0·20	18,000	13,700	16,500	10	In British Territory.
	85						In Nepal.
	67						Reconnoissance in Nepal.
„ J. S. Pocock, ...	294	0·30	18,500	15,500	19,000	39	
„ R. F. Warwick, ...	163	0·50	12,500	11,000	14,200	5	
TOTALS ...	959	0·33	16,333	13,600	...	54	

N. B.—Total of Topographical work executed on both scales 1,599 square miles.

E. C. RYALL,

Asst. Supdt., G. T. Survey of India,
in charge, Kumaon and Garhwal Party.

Extract from the Narrative Report, dated 23rd August 1877, of Captain A. W. Baird, R.E., in charge Tidal and Leveling Operations.

Only one detachment of the party to carry on leveling.

2. In June 1876, I availed myself of three months' privilege leave and went to England. Prior to my departure, I was informed that it was most probable I should have to remain there to finish off the reductions of the tidal observations in co-operation with Mr. Roberts of the Nautical Almanac Office. I had to settle, therefore, the work for the next field season before I left. In the former season two detachments of the party were at work, carrying on different lines of levels simultaneously; it was of course only necessary for me to arrange for one detachment to be at work, should I not return in time to take the field.

3. Major (now Lieutenant-Colonel) Haig took charge of the party on my departure. I drew up a memorandum for his information, giving all the details of the lines of levels, and the branch lines which should be executed so as to connect irrigation, railway, and other levels. With this memorandum for his guidance, Mr. Rendell (who had charge of the detachment) had no trouble in carrying out the work required.

6. Mr. Rendell reports :—

Difficulty in recognising Irrigation Department bench-marks.

"My first duty was to make enquiries and search for the Irrigation bench-marks round about Sánand. I spent a week in useless search, although I had a map by me shewing their position. This was due to the fact that the majority of the Irrigation bench-marks are situated on the roots of trees, which I was not aware of at the time; I looked for something more substantial: however, on communicating with Major Haig, he sent me a complete list of the bench-marks I required, with a full description of each, and which contained the names of the village officials to whose care they were handed over. With this before me, I found no difficulty in connecting a number of Irrigation bench-marks extending over Sheets 80, 81, 8, and 9 of the Guzerat Survey."

Work commenced on main line and branch to Páli, &c.

7. After completing this, Mr. Rendell marched to Mehmadabad, where he arrived on the 23rd December. He then connected Jinjhar H. S. with the Mehmadabad bench-mark by a branch line about 6 miles long, and afterwards commenced work on the main line of levels which was being carried along the railway line. By the 2nd January he reached Ánand Railway Station, and then drove a branch line along the railway from Ánand to Páli, a distance of 32 miles, and connected Páli and Poeda stations of the Great Trigonometrical Survey triangulation.

Branch line to Cambay.

8. The work on the main line was recommenced on the 24th January, and by the 11th February the main line had been carried as far as Wásad. From this a branch line was taken to Cambay, and a Great Trigonometrical Survey bench-mark was embedded near the town, and the Trigonometrical Station (Cambay Factory) was also connected. This branch line was 33 miles in length, and along it 20 pucka points or bench-marks were connected.

Pucka points connected at Baroda.

9. The main line was then continued as far as Baroda, where a bench-mark was laid down at the Railway Station, and another in the Cantonment, and several pucka points were also connected in Baroda, such as the steps of the dâk bungalow, the pavement at the bottom of the clock tower, &c., and also the top of the clock tower, being a Great Trigonometrical Station. The heights of the points fixed at Baroda were supplied to the Executive Engineer for Irrigation at Baroda, to enable him to refer all his levels in future to mean level of sea.

Branch line to Dabhoi and Sidpur H.S.

10. The main line was then continued, and on the 23rd February had reached Meagám, where a branch line was carried to Sidpur H. S., a distance of 30 miles, 23½ of which extended over the narrow gauge Railway of his Highness the Guicwar, which goes to Dabhoie. Bench-marks and pucka points were connected *en route*.

11. By the 9th March the main line had been carried as far as Broach. Of the work on the main line beyond this, Mr. Rendell reports :—

Levelling over the Nerbudda, the Railway bridge being partially destroyed.

"Owing to a good portion of the Nerbudda bridge (nearly half) having been washed away during the previous monsoon, I anticipated great difficulty in carrying my line of levels across the river, which at this point is nearly one mile broad. I found that a temporary structure had been erected over which trains passed at a very slow rate of speed, this structure being connected with the portion of the bridge that remained standing, by a diversion having a decline of something like 1 in 12. One or two pucka points on the north and south banks of the river were also fixed, and their heights notified to the Railway Engineer in charge of the bridge, who was desirous of obtaining accurate data to start from, in connection with the new bridge which is about to be constructed.

Surat was reached by the end of March, and several bench-marks in the vicinity of the town were connected.

Irrigation levels of the Tapti project connected.

12. In continuing the main line, several of the Irrigation Department levels in connection with the Tapti project were connected between Ankleswar and Sachin.

Main line closed.

13. From a point about 3 miles south of Bulsar a branch line was run to Parnera H. S., a principal station of the Northern Concan series, and by 28th April the main line was closed for the season at Damaun Railway Station; a branch line was carried from this to the town of Damaun, a distance of 6 miles, where a Great Trigonometrical Survey bench-mark was laid down.

General execution of the leveling.

14. The operations were carried on throughout by two independent levelers according to the rigid rules in force in this Department. Mr. Rendell reports :—

"In no case was the discrepancy between the two instruments allowed to exceed ·006 of a foot; and, indeed, instances are rare where a difference of ·005 of a foot was allowed to pass without repeating the observations."

The difference between the closing results of the two levels was 0·090 foot, and the greatest difference at any end of any section during the season was 0·128 of a foot, which was at 144 miles from starting.

Comparision of the staves.

15. A comparison of the staves with the portable standard bar was made four times during the season, *viz.*, at Sánand, Meagam, Surat, and Damaun.

Height at Railway Stations connected.

16. The heights of the rails opposite the booking offices of 35 Railway Stations were ascertained, and the average error of the heights as given by the Railway authorities is + 5·1 feet. The greatest error was at Palej, *viz.*, + 8·0 feet, and the least at Broach + 2·5 feet. At Broach the error of the Railway height is 2·5 feet, and at Ankleswar it is 6·2 feet, and the distance is only 5½ miles; this would give an error of 0·67 foot per mile. Similarly, between Bulsar and Dungri, also a distance of 5½ miles, there would be an error of 0·67 foot per mile, but errors of this magnitude are of course exceptional.

Outturn of work during field season.

17. The following statement shews the amount of leveling executed by the party.

Double leveling, main line	183⅓	miles.
ditto, branch line	174¾	"
TOTAL ...	358¼	"
Single leveling loop line	16¼	"
Number of Great Trigonometrical Stations connected ...	16	
Number of Great Trigonometrical Survey bench-marks embedded and connected	31	
Railway heights connected	39	
Number of Irrigation heights	40	
Number of other pucka points duly inscribed and connected	180	

Loop line, Sánand to Ahmedabad.

19. As the levels supplied to the Officer in charge, Guzerat Party, by the Executive Engineer, Ahmedabad, for incorporation in the Guzerat maps, would not stand any single correction, that is, the correction applied to one set of levels would not suit another set which had one station in common, I sent up a leveler and a few men to run a loop line from Sánand to Ahmedabad, and pick up the points as given in the list of levels in question. This loop line emanated from a point at Sánand, connected with the Great Trigonometrical Survey bench-mark there, by double leveling and closed on a point at Ahmedabad, also connected by double leveling with the Great Trigonometrical Survey bench-mark at Ahmedabad. The closing error of the single line was 0·044.

Mr. Rendell's services.

21. The out-turn of leveling for the season I consider excellent, and Mr. Rendell deserves much credit for this. I take this opportunity of bringing Mr. Rendell's services prominently to notice. He has been four years in his present grade in the Department. In August 1875 I also reported favorably on him, with a view to his being promoted; but the vacancy in the next higher grade at that time was, I believe, absorbed on account of reductions in the Survey Department.

Work in the office during recess.

23. Since coming into recess quarters, the duplicate Sheets have all been completed and brought up. The description of bench-marks and all pucka points connected have been made out in duplicate, with sketches of the points, where necessary, to accompany the level sheets. The abstract of heights, and computation of unit corrections, also table of comparison of Great Trigonometrical heights determined trigonometrically and by spirit-leveling, have been completed. Similar tables for Railway heights and charts, shewing the routes of leveling in detail, are all nearly completed; and the forms for the preservation of the stations have been filled up and handed over to the different authorities, and receipts obtained for the safe custody of the stations. In fact the whole work in connection with the leveling operations will in a few weeks have been completed and despatched to the head quarter office.

Extract from the Narrative Report, dated 17th October 1877, of Captain W. J. Heaviside, R. E., in charge No. 1 extra party.

(1). The field season of 1876-77 was commenced by this party more than usually late; in the first place because the first station for observations was Vizagapatam, which is exposed to the full force of the north-east monsoon and where clear nights for observing were not to be expected until January; in the second place owing to the heavy nature of the computations of the previous season's work, which it was considered most desirable to clear off before leaving recess quarters. Moreover, I had been warned that I might have to take up latitude observations, towards the close of the field season, with one of the zenith sectors, and as these instruments were new to me, while my colleague Captain Campbell was well acquainted with both of them, I availed myself of the opportunity of his presence to have some practice with them before taking the field. Both instruments were put up with Captain Campbell's assistance and their peculiarities pointed out by him, after which I had one of them carried out to the south-west station of the Bangalore base line and took observations there on two or three nights, subsequently reducing the observations according to the forms previously used by Major Herschel. When Major Herschel and Captain Campbell were employed in latitude work with the zenith sectors, they adopted the admirable system of giving full accounts of the whole procedure adopted each season, both in the observations and in the computations, pointing out any idiosyncracies that were remarked in the instruments and any peculiarities exhibited by the results. These summaries or, as they may be called, histories of the work are bound up with the computations of each season's work, and embracing, as they do, all the experiences obtained with these instruments, proved of great value to me, and must prove so to any one who has to use the sectors in the future. The same system of historical record has been adopted with regard to the longitude operations and the instruments employed in that work.

Before taking the field, the clocks, chronographs, and telescopes employed in the Longitude work were also set up and overhauled; transits were taken with both telescopes for a determination of the personal equation between Captain Campbell and myself, and some circumpolar stars were observed for the re-determination of the wire intervals of No. 1 telescope. A curious circumstance may here be mentioned with regard to the effect of a firm attachment on the rate of an astronomical clock. When clock No. 1134 was first set going, there were no convenient points in the room to attach it to, and it was set up with the base of the clock case merely resting on the floor which was firm and made of cement in the usual Indian fashion. It was found, on comparison with a chronometer, that when the bob of the pendulum was screwed up to its full extent the clock in this position lost at a uniform rate of 123 seconds a day. It was thought that this must be due to an escape of mercury from the cistern, but as no such escape had been detected, it was considered advisable, before proceeding to open out the mercury cistern, to have some firm supports arranged in a doorway, to which the clock case was screwed up in the usual manner. The clock when thus fixed, and with the bob screwed up to its full extent as before, was then found to gain 79 seconds a day, shewing a difference in rate of 3 minutes 22 seconds a day due to the change in the manner of supporting the clock case. It appears from this that the whole clock case, when not fixed, moved to a certain extent with each oscillation, thereby changing the position of the point of suspension of the pendulum and increasing the amplitude of the arc of vibration.

(2). The equipment of the party was sent off to Madras by goods' train on the 21st December, and I followed on the 26th, but the equipment did not arrive until the 30th. I had intended to leave Madras by a steamer due on the 2nd of January, but that steamer broke down and this circumstance, together with the irregularity of the steamer service caused by the immense rice trade that had sprung up to meet the scarcity prevailing in Madras, prevented me from leaving until the 10th of January. I arrived at Vizagapatam on the 13th and found that Mr. Bond had everything in readiness for me. From this station the two arcs, Vizagapatam—Madras, Vizagapatam—Bellary were to be measured.

(3). It was now the middle of January when fine weather might be expected, but the work was excessively delayed by abnormally cloudy weather, quite of a monsoon type. The first arc was not completed until the 1st of February, and when Captain Campbell had moved up to Bellary and was ready to commence the second arc, the weather had become so stormy that we were unable to do any satisfactory work until the 17th of February, eventually finishing this arc on the 25th.

Although, as a rule, cloudy nights entail on the observer almost as much sitting up as fine nights do, since there is always fair expectation of a break, yet on this occasion the clouds were so dense, heavy and continual, that on several nights no attempt was made to observe. A good deal of office work was in consequence got through during the day, the transcription of the chronograph sheets and the reductions of the first arc being well advanced before the observations for the second were commenced. At Captain Campbell's suggestion, a referring mark for the transit was built at Vizagapatam, nearly in the meridian, on a hill about four miles to the north of the station, so that in the event of failures to obtain circumpolar stars for azimuth, on nights when transit stars were observed, a value of azimuth might still be deduced for that date from micrometer intersections of the referring lamp, night by night. As it so happened, azimuth stars were obtained whenever they were required, yet the referring mark was a great source of comfort under cloudy skies, and in future whenever a convenient site can be obtained, a referring mark should be arranged for by the Assistant who prepares the longitude station, and in low latitude other advantages might well be sacrificed to obtain such a site.

(4). The party eventually left Vizagapatam for Mangalore on the 28th of February, and reached Madras on the 3rd of March. The instrument, and camp equipage were left on board the steamer to go round by sea, but the individuals of the party, both Native and European disembarked, and after six days sojourn in Madras crossed the peninsula by rail to Beypur, re-embarking there on board the same steamer on the 15th of March. This appeared to me, for many reasons, a far better arrangement than the alternative of sending the whole party round by sea. In the first place I was in daily anticipation of hearing that the Government of India had sanctioned a proposal for a determination of the difference of longitude between Bombay and Suez, in which case it was desirable that I should proceed at once to Bombay; in the second place an opportunity was thus offered and secured of doing six or seven days' good work in the reductions of the observations on shore, in place of practically nothing on boardship; and in the third place the Native Establishment was composed, with one exception, of Hindoos who eat nothing but raw or parched grain on boardship, and I did not feel justified in sending these men round by sea.

We did not arrive at Mangalore until the 18th March, where pillars for the instruments had been built a month previously by Mr. Neuville, a few yards south of the positions of the pillars employed in 1872-73.

(5). Regular work was commenced on the arc Mangolore—Bombay on the night of the 22nd. On the 23rd, I heard that sanction had been obtained for the determination of the difference of longitude between Bombay and Suez. The observing season was now far advanced, and to complete the connection of Bombay with Suez this season, it was essential that the observations in Bombay should be undertaken before the gathering of the monsoon clouds, to effect which it appeared necessary for me to start for Bombay by the next steamer. As the steamer was not likely to arrive until the 31st there would, under ordinary circumstances, have been ample time to complete the usual six nights' observations; but we were unfortunate in this respect. I was unable to work on the 23rd, owing to an inflamed eye. On the 27th the telegraph line was interrupted, and about noon on the 28th, I heard that the steamer would be in before her time early next morning, and I had a hard day's work to get everything down and packed up in time to start by her. The Arc Mangalore—Bombay is therefore dependent on only four nights' work, which however is probably sufficient to give a good result.

(6). The party left Mangalore by sea on the 29th, and landed in Bombay on the morning of the 2nd of April. A fortnight was spent there with Captain Campbell in consulting and arranging a system for cable communication; in the determination of personal equation, and in various preliminaries connected with the novel work we were about to undertake.

The longitude station adopted at Bombay and used for the previous work on land lines was in the grounds of the Colaba Observatory, about there miles distant from the cable office. On land lines we had been able to work directly from station to station, but now that the signals had to be transmitted either to or from the cable office, this distance became a great disadvantage; it entailed the presence of an assistant at the cable office for the greater part of the night to look after the signals and prevented verbal communications in case difficulties arose, as was likely to happen with a new system on its trial. But there were so many objections to changing the station, that we had to do our best as it was, and the disadvantages, when the work once got into swing, were less than had been anticipated.

Captain Campbell was ready at Aden on the 24th of April, and on that night we had some preliminary practice, commencing regular work on the Arc Bombay—Aden on the 25th.

(7.) By the first system adopted for the interchange of signals, the clock at Colaba was placed in connexion with a relay at the cable office, which it worked by the usual break of contact at each second. During the times that signals were being exchanged between Bombay and Aden, the relay was placed in connexion with the electrified ink of the Thomson syphon recorder, so that, by a simple arrangement, whenever the relay broke contact, the electricity passed from the ink to earth, thus arresting the flow of ink through the syphon recorder and marking each second of the clock amongst the cable signals on the Tape. It was found however, after two nights trial that this system did not give satisfactory results, and on the 27th Captain Campbell telegraphed the details of a new system which proved a great success. This system, which I believe to be original, and for which Captain Campbell deserves much credit, consists in placing a relay in the circuit of the cable battery between the signalling key and the battery, so that whenever the key is pressed the current passes out through the cable as usual, merely weakened by the additional length of the relay coils, and at the same time works the relay. At Bombay this relay was in connection with one of the pen armatures of the chronograph at Colaba, so that each signal sent from Bombay to Aden was recorded on the chronograph at Colaba alongside the clock signals. Two days were spent in perfecting this system, after which our work proceeded very smoothly, so far as the comparisons were concerned, although retarded somewhat by cloudy nights at Aden, where they were least anticipated. The Arc Bombay—Aden was completed on the 9th of May.

(8.) The party left Bombay by steamer on the 14th of May and arrived at Aden on the 21st. The Telegraph Office at Aden was, at this time, in course of removal from the house near the landing place, to the new block of building in Telegraph Bay, whence the cable signalling is conducted. Mr. Stacey, the Superintendent of the Telegraph Company, kindly placed at my disposal a row of thatched rooms which his staff had recently vacated and which enabled me and my assistants to live on the spot close to the longitude station and to the cable office.

The work at Aden proceeded perfectly smoothly and the arc Aden—Suez was completed on the 30th of May, and is the only Arc of the season where a succession of five clear nights were experienced simultaneously at both stations.

(9.) During the time I was observing at Aden, Mr. Connor carried a triangulation across the Peninsula to connect the longitude station with the Marshag light-house and with Lord Lindsay's station for the observation of the Transit of Venus. The triangulation started from a base line about $\frac{1}{4}$ of a mile long, measured twice over with a metallic tape which had been compared with a standard bar at Dehra. It was not originally intended to mark any but a few of the most important stations of this triangulation; but when Mr. Connor was selecting the stations, he found the hill tops to be in such a loose crumbling state as to require platforms to be constructed for the Theodolite, and, as a mason was required for this purpose, mark-stones with the usual circle and dot were placed at all the stations, except Lord Lindsay's. This station had previously been marked by a carronade sunk to ground level, but a mark-stone was in course of preparation, and the Assistant Resident informed me it would soon be placed on a pillar to be built over the station, which it so happens is just outside the building in which the pendulums were swung by me in 1873.

(10.) The interval of a week which elapsed between the completion of the longitude observations and the arrival of the next steamer was spent in overlooking this triangulation, in taking some latitude observations, reading off chronograph sheets and packing up. On the 7th of June the party embarked for Bombay on board the *Avoca*, in which Captain Campbell's party had left Suez, and the combined parties arrived in Bombay under my charge on the 14th; the instruments and camp equipment were sent thence by goods' train to Poona, where office was opened and the recess season commenced on the 22nd of June.

(11.) The boxes containing the instrumental equipment have experienced some rather rough usage this season. Both at Vizagapatam and Aden everything had to be carried about by most unruly coolies, and at each place, up and down a steep hill where the coolies could not be well controlled; the equipment has twice passed in cargo-boats through heavy surf; twelve times it has been slung either to be shipped or unshipped; and although the boardship method of slinging is not quite so hazardous as it looks at first sight, yet it is not devoid of considerable danger to instruments, as was proved at Aden by a collimator box slipping out of the slings and rolling off the cargo-boat into the sea; the box, being a well-made English one, fortunately floated just long enough to enable it to be secured, without resorting to the amphibious Somali for its recovery, and the collimator inside the box sustained no damage beyond the wetting, which however was so thorough as to have partly corroded some of the smaller screws. Otherwise, although the boxes have suffered in their six months' travels, the instruments have remained in good order, the breakage of a glass cover of a hanging level being the only injury detected.

(12.) *Mr. C. J. Neuville* joined the party on the 7th of November 1876 in place of Mr. H. E. T. Keelan who had been transferred to the Mysore Survey. After being instructed in the forms of computations in use in the party, and being furnished with plans and memoranda, he left Bangalore on the 17th of December for Mangalore where he constructed the longitude station, and where it was intended he should remain until the arrival of this party. But in the *interim* his services were required by Captain Campbell at Madras, and so it arose that he joined and remained with Captain Campbell for the rest of the field season.

13. *Mr. E. T. Connor* joined the party in Bombay early in April. As he had not previously been employed in astronomical work, he required a good deal of coaching; but he mastered the work of recording and the preliminary computations rapidly, and soon become a useful assistant.

(14.) *Mr J. Bond.*—Mr. Bond was with this party during the whole field season. He left Bangalore on the 14th of December for Vizagapatam, and with good judgment he there secured, at a low rent, a house in the grounds of which he built the transit and collimator pillars in an excellent situation, about 100 yards from the trigonometrical hill station of Meppen, the clock pillar being erected in a room of the house where the clock was well protected from currents of air or sudden changes of temperature. He executed the triangulation necessary to connect the longitude station with the coast series, protected and transferred to the local officials two stations, acted as my recorder, and during the cloudy weather we experienced at Vizagapatam he made great advances in the computations. At Bombay he received some instruction in taking transits, so that, if the weather there proved as cloudy as was anticipated, he might take a few stars during some portion of the night; but the fine weather experienced rendered this unnecessary and his duties lay at the cable office where, at stated times, he sent signals simultaneously to Captain Campbell at Aden and to me at Colaba. At Aden he was similarly employed, but as the longitude station was close to the cable office there, he was able to act as my recorder in the intervals between the comparisons. Mr. Bond has performed his duties both in the field and during the recess in a very satisfactory manner. He has displayed good judgment, skill, and tact when he had to act independently, as for instance at Vizagapatam, where he chose the position of the longitude station. and at Bombay where he had control of the cable signalling during the time of the comparisons and he has worked well at the computations.

(15.) The native establishment consists, with one exception, of Hindoos from the North-Western Provinces and their custom of refusing to eat cooked food on boardship and subsisting only on dry and parched grain with a little *goor*, unfits them for long sea voyages, and on the way from Madras to Vizagapatam a duffadar who had but recently recovered from diarrhœa died in a few hours from an acute return of the disease brought on by this unwholesome diet. This was the only casualty during the season, and the health of the men has otherwise been very good; the sea voyages were cheerfully undertaken by them, and no objections were raised even to the long sea voyage over the *Kali pani* to Aden and back. I had expected difficulties at Aden with the natives about the condensed water; but when they found that it was drunk by other Hindoos and that the canal water was exceedingly brackish, they used it after a few grumbles.

(16.) I have to acknowledge much assistance, in the course of the season's work, from the several Telegraph officials with whom I came in contact. I am more particularly indebted to Mr. Flindell, the Superintendent of the Ganjam Division, who, when his office at Vizagapatam was short of signallers, and I was much troubled by induced currents, came up to the Observatory at night and spent some hours in signalling for me with his own hands. In Bombay, Mr. B. Smith, the Superintendent of the Eastern Telegraph Company, and his assistants gave us every facility for carrying on the work, in the first instance explaining the cable signalling instruments which were quite new to me, and subsequently, when difficulties arose, they were always ready to afford personal assistance, which must frequently have been rendered with great inconvenience to themselves. I have also to thank Major Gambier, R. E., the Superintendent of Military Works at Aden, and Mr. F. Chambers, who, in the absence of his brother on furlough, is in charge of the Colaba Observatory, for many little services rendered to me in connection with the work.

(17.) In conclusion, I may remark that I have purposely avoided going into details regarding the systems and methods followed in our operations, as Captain Campbell has, in his report, entered fully into these matters.

Extract from the Narrative Report, dated 19th October 1877, of Captain (now Major) W. M. Campbell, R.E., Officiating Deputy Superintendent, 2nd grade.

Employment.

1. During the past field season Captain Heaviside and myself have continued the determination of differential longitudes by means of the electric telegraph.

Operations of 1875-76.

2. At the date of my last report we were approaching the completion of the reductions of such observations made in season 1875-76, and I was enabled to submit the results in a postscript. Shortly afterwards however changes were found advisable in the method of reduction, which caused considerable re-computation, and altered the results, though only by small quantities. I now append the final results of 1875-76, and will revert to the cause of the alteration in a later part of this report (paragraph 41).

Programme for 1876-77.

3. By considerable exertion the reductions were completed by the end of the year, when we separated for our cold season's observations, the programme proposed for which was as follows:—The measurements of arcs Vizagapatam—Madras, Vizagapatam—Bellary, and Mangalore—Bombay. Besides these, the measurement between Bombay, Aden, and Suez by cable was contemplated, if the necessary sanction could be obtained. This measurement was urgently advocated by the Astronomer Royal, Sir George Airy, in order to complete the connection between Greenwich and Madras, the European section of which, between Greenwich and Suez, had already been executed on the occasion of the Transit of Venus in 1874.

Bombay—Suez Measurement.

Movements.

4. As the preliminary operation of the season, we determined our personal equation in December before leaving Bangalore. For the first measurement, Vizagapatam—Madras, Captain Heaviside went to Vizagapatam and I to Madras. I afterwards moved to Bellary while he remained at Vizagapatam, for the measurement Vizagapatam—Bellary, on completion of which we moved simultaneously to Bombay and Mangalore, respectively, for the measurement of that arc.

Progress impeded by weather.

5. The season proved particularly unfavourable for observation owing to clouds, which caused so much delay, that we did not begin observations between Bombay and Mangalore until 22nd March. Up to this date the question of carrying on the operations by cable to Aden and Suez was still undecided, but on 23rd March I heard from Colonel Walker by telegraph, that the sanction of Government had been obtained. The season was so far advanced that no time was to be lost, and we therefore curtailed our ordinary programme of measurement between Mangalore and Bombay by two days, in order that Captain Heaviside might not lose the first weekly steamer to Bombay, where he arrived on 1st April.

Bombay—Suez measurement sanctioned.

Preparations for cable work.

6. On 2nd April I despatched Mr. Neuville to Aden by P. & O. Steamer, to make all the preparations there. I had abundance of employment in Bombay in connection with the details of working by cable, both before and after Captain Heaviside arrived from Mangalore, and we finally settled on a method of working which promised to be exceedingly simple and efficacious. I shall revert in the proper place to this subject. We also observed on four nights for personal equation, after which I packed up my instruments and proceeded to Aden by the P. & O. Steamer of the 16th April.

Captain Campbell at Aden.

7. Arriving at Aden on 23rd, I found the preparations in a fairly forward state, and no time was lost in getting ready for observations. The observatory was conveniently situated about 150 yards from, and some 60 feet above, the new cable office, which had lately between completed. We began observations through the cable on 25th April, and worked (under great difficulties at Aden) on that night and the next on the system which we had fixed upon in Bombay. On the latter date I came to the conclusion that a change of method was absolutely necessary and hit on a happy alternative plan (described in paragraph 26 *seq.*), which we introduced on the 28th, after which we had no difficulty with the cable work.

Clouds at Aden.

The weather had caused us much anxiety, as the season was very late for star observations at Bombay; but fortunately Captain Heaviside enjoyed fine clear nights there, while at Aden, where we had reckoned pretty confidently on clear skies, I was troubled with frequent clouds lying low on the horizon, so as seriously to interfere with azimuth determinations, which are accordingly a weak point of the observations.

Captain Campbell proceeds to Suez, and Captain Heaviside to Aden.

8. We closed observations on 9th May, and I left Aden for Suez by P. & O. Steamer on the 14th. Mr. Neuville had preceded me by the mail of 30th April, and on reaching Suez on 20th May, I found the station building ready to receive the instruments, which were immediately put up. Captain Heaviside being also ready at Aden on 25th we began observations on that day, and continued nightly without interruption or difficulty until 30th,

when, having obtained six nights of good observations, we considered the measurement complete and closed work for the season.

Return of the parties to India.

Captain Campbell takes privilege leave.

9. I fortunately succeeded in despatching Mr. Neuville with the men and instruments per P. & O. Steamer of 1st June, which picked up Captain Heaviside's party at Aden on the 7th. Having been granted three months' privilege leave on completion of the field operations, I took advantage of it on 4th June. Captain Heaviside proceeded direct to Poona for recess quarters, where I joined him on the expiration of my leave on 30th August, since which date I have been steadily employed on the reductions. These are now in a forward state, and I hope to be able to give some results as a postscript to this report.

Measurements made by land wires.

10. With regard to the three measurements by land wires which we completed, I may remark that, although the distances were greater than we had formerly attempted, we found no difficulty whatever on that account. This applies particularly to the measurement Mangalore—Bombay, between which places the course of the wire is so circuitous that its length aggregates about 1,000 miles, and moreover the section near Mangalore is not so well insulated as is generally the case. We were led to expect great difficulty in exchanging signals direct between these two places, without intermediate relays, but with batteries of about 90 cells all anxiety on this head proved groundless. The three measurements obtained complete two more circuits, *viz.*, Vizagapatam—Madras—Bellary, and Madras—Mangalore—Bombay, the observations of 1872-73 between Madras—Mangalore being involved in the latter.

Circuits completed.

Method of working.

11. In these measurements we followed the methods employed during the preceding season, with but slight modifications and additions. The use of the telegraph wire was always obtained for the whole period of observations nightly, and the transits were observed at both stations with one clock, each being used alternately. Clock comparisons were only taken as a precaution, and have not been read off or used in the reductions except where occasionally necessary.

Precautions introduced.

Some extra precautions dictated by experience were observed in the commutator arrangements, with a view to eliminating as much as possible the effects of interference of currents, which it is impossible altogether to avoid.

Faults of apparatus.

The fact is that our magnetic recorders are not at all what they should be, because when I got them made up in 1875, I was obliged to use the materials available, *viz.*, the electro-magnets belonging to the original form of the apparatus. These were originally intended for use in connection with long lines as well as short local circuits, and they are not at all adapted for the latter, which is now the only way in which they are employed; the importance of this fact has grown upon us with experience. By a change in the connections of the pair of coils forming each magnet, which I introduced in Bombay in April, the total resistance was divided by four, and reduced thereby to an average of 170 units for all. This was found a great improvement, but it might be carried much farther, coils of about 30 units resistance being probably those best adapted for our purpose.

Partial correction.

Source of discrepancies found in results—
(1)—Astronomical.
(2)—Electrical.

12. With regard to the source of the discrepancies which sometimes occur in our results, some question has been raised as to the comparative responsibility of the astronomical and the electrical parts of the observations. I am afraid that the chief blame must be awarded to the former. The electrical part may be divided into two portions, *viz.*, as affected by (1) the arrangements inside our observatories, and (2) the line connecting the two stations. The previous remarks show that I do not consider the first of these as above suspicion, and that this part of our equipment is open to improvements, but I should rank the errors likely to arise on this account as quite secondary in importance to the astronomical errors. As to the second, the electrical behaviour of the line between the observatories, I do not for a moment believe that any appreciable error can be laid to its charge, provided there is direct communication without relays, as has always been the case in our operations. In this opinion I think I should be supported by that of all electricians.

Preliminary experiments for working by cable.

13. On receiving the order for observing between Bombay and Suez, I at once began the preliminary preparations and experiments, which were rendered necessary by the fact of cable work being quite novel to us.

Method of observing.

As regards the method of carrying out the observations, the use of the cable would compel us to abandon the system of using the same clock for transits at both stations, for two reasons—

(1). It seems impossible to transmit the beats of a clock through the cable, and record them on the distant chronograph; and (2), even if this could be done, the use of the cable could not be obtained for sufficiently long periods, for the night is the busiest part of the 24 hours on these cables. We were therefore obliged to have recourse to the method of comparing clocks at fixed times, and observing transits with each clock locally before and after each set of comparisons.

14. My great object was to contrive a method of recording mechanically at both stations, signals sent alternately from each, so as to obtain a comparison of clocks free from any personal equation. So far as I am aware this had never previously been accomplished, a personal equation having always entered in the observation and record of the reflecting galvanometer, with which I believe all longitude observations by means of electric cables have hitherto been carried out. I hoped to effect my object by means of the Thomson Syphon Recorder, which was fortunately in use on the Bombay—Suez Cable. This is a beautiful instrument recently invented by Sir William Thomson, a few descriptive remarks on which will not here be out of place.

Method of comparing clocks through cable considered.

15. A very fine syphon of glass is suspended in the most delicate manner, so as to be affected by the currents passing through the cable, which jerk it in opposite directions according as they are positive or negative. The upper end of the syphon dips into a reservoir of ink (aniline blue), and the lower end is very nearly in contact with the paper tape on which the record is to be produced, but the calibre of the syphon is so very fine that the ink must be forced through it, which is done in the following way :—

The syphon recorder.

At the top of the instrument there is a wide wheel about 6 inches diameter and nearly the same width, technically called the "mouse-mill," which is driven by an electro-magnet below it. The motion of the "mouse-mill" serves two ends—(1) it draws the paper tape past the syphon, at a rate which can be regulated at pleasure with, as we found, great uniformity : (2) it induces a powerful current of statical electricity, which is conducted by a brass rod terminating in a point, towards a disc of brass, the distance of which from the point of the rod can be varied. This disc is in connection with the ink reservoir, and thus the ink becomes electrified to a degree which is regulated by the distance between the point of the rod and the disc. The insulation of the mouse-mill and the ink reservoir must be very perfect, as the static electricity, which is of high tension, will leak away through the slightest opening. The paper tape affords the nearest conductor for the escape of the electricity in the ink to earth, and this suffices to force the ink through the syphon and across the minute interval between it and the tape.

The "mouse-mill."

Electrification of ink.

When no current is passing through the cable the syphon remains at rest, and traces a straight line along the centre of the tape, which is called the "Zero line." Positive and negative currents jerk the syphon aside in opposite directions, so as to mark signals on opposite sides of the Zero line. When working the cable on the 'simplex' method, all signals transmitted and received are recorded on the tape, the former being very sharply defined as compared with the latter; but when arranged for 'duplex' working, the signals transmitted are not locally recorded.

Signals produced.

16. Our observatory at Bombay (Colaba) was about three miles from the Telegraph Office, and as all connections between land wires and cable are strongly objected to, on account of the risk of damage to the latter by lightning, it was necessary that the signals for comparison of clocks through the cable should be made in the Telegraph Office.

Necessity of signalling from Cable Office.

17. The first idea was that at each station the signals transmitted through the cable should be recorded on the local chronograph, as well as on the local and distant tapes—single signals being sent from each end alternately. This would afford a record of a series of received signals B, B, each occurring between two transmitted signals A, A, so that by measuring the intervals on the tape, and assuming uniformity of its motion, the former, B, B, may be interpolated in terms of the latter, A, A (see fig. 2, plate facing page). Now the signals A, A, B, B, being also recorded on the local chronographs their exact local times are known, and thus the difference between the clocks is arrived at by the observations at each station, only affected by retardation of signals, which enters with different signs at the two ends, and may therefore be considered as cancelled when a mean of both results is taken.

A method of comparing clocks described.

The only objection I saw to this method, besides the fact of the reductions being laborious, was being obliged to trust the rate of the tape; but experience has since proved that each series of signals (A, A, B, B) can be transmitted at intervals of less than three seconds, and that for such intervals the rate of the tape is quite sufficiently good. While considering the best method of arranging for the record on the chronograph of the signals transmitted through the cable, which presented some difficulties, another system occurred to me which promised many superior advantages.

Objections and difficulties.

18. It has been already remarked that great attention is requisite to keep the ink reservoir perfectly insulated, failing which the flow of ink is at once arrested. With reference to this it was pointed out to me as an interesting fact, that a touch of the finger, or even of a pencil, on the reservoir sufficed to stop the ink, and it immediately struck me that we might so connect our clock with

A more promising method described.

the reservoir as to put the ink to earth at each second, thereby marking the seconds on the tape by breaks in the ink line.

Put in execution.

This was accomplished with some little trouble in the following way:—A polarised relay was placed on the table beside the syphon recorder, and the signals from the clock passed through it, so as to work the armature at each beat. A fine wire was passed from the ink reservoir to the armature, so that at each beat connection with earth was obtained. This failed, because the insulation of the relay was not sufficiently good, and the mere contact with the table gave sufficient leakage to stop the ink altogether, independently of the position of the armature. A small contrivance fitted to the relay, however, effected our object, and we had the satisfaction of procuring a beautiful record of seconds on the tape by means of little breaks in the ink line.

Exchange and record of signals.

The record of a comparison of clocks then took this form. Hand signals by key were transmitted from each station in alternate series (instead of in series of alternate signals as above), and recorded on both cable tapes, while on each tape the seconds were marked by the local clock, and thus the local and distant times of each signal could be compared with great facility.

Advantages of second method.

19. The advantages of this system over the former were that—(1) The rate of the tape was only relied on for intervals of one second; (2) the results of comparison could be deduced with very much less labor; (3) a comparison could be carried on without in any way interfering with the work in the observatory, because the connection of the clock with the relay, &c., was under the control of the signaller in the Telegraph Office, who only required to note certain times on the tape by a clock or watch (which had been compared with that of the observatory), in order that the observatory clock's record on the tape might be properly identified as regards minutes. The beginning of each minute was, of course, marked on the cable tape, just as on the chronograph sheets, by the omission of one signal. These were all great advantages, and the last not the least so, as it permitted the observation of transits without interruption, and relieved the observer of all anxiety on account of the clock comparisons.

Comparison of clocks named—
(1) by longitude signals,
(2) by ink-arrest signals.

The first of these methods may be known as comparison of clocks by "longitude signals," and the second by "ink-arrest signals," and if my description has been followed, it will be evident that nothing in the shape of a personal equation of observation enters into either, though it is possible that personal peculiarities of using the signalling key may produce minute variations in the retardation of the signals.

"Ink-arrest" method adopted.

20. The success of continued experiments with the "ink-arrest" method at Bombay was most satisfactory to both of us, and we agreed to adopt it for the observations. It need hardly be pointed out that this arrangement involves no connection between the land line and the cable, and therefore introduces no danger to the latter.

Retardation of signals.

21. It is well known that the retardation of a signal through a cable is very much greater than that of a signal transmitted by a land wire, and in the case of long cables it becomes a very considerable quantity. The lengths of the cables used by us are, between Bombay and Aden 2,172, and between Aden and Suez 1,864 miles. In such observations as ours, one must be content with assuming generally that the retardation affects signals equally in both directions, in which case its effect is perfectly eliminated by the method of working. Unpleasant suspicions, however, will occur that this may not be the case, and that the retardation may be affected by the direction of the signal relatively to the magnetic poles, or the rotatory motion of the earth, or by the direction of existing earth currents, or above all by the nature of the current used, whether by zinc or copper to earth at sending station.

Original precaution against variation.

22. When Major Herschel and I began electro-longitude operations in India in 1872-73, we acted on these suspicions, and introduced regular changes of current during observations, with a view to cancel the effect of such variations, and even if possible to measure some of them.

Precautions abandoned on land lines.

Later however I came to the conclusion that the retardation on land lines being so very minute a quantity, and its variations therefore presumably much more minute, it was vain to hope to detect these variations by means of observations affected by much more serious causes of errors. If our reports for season 1872-73 be referred to, it will be seen that different values of retardation according to direction and nature of current were assigned, but I added what appeared a probable reason why the apparent differences should be fictitious, and due to our apparatus, and further experience has only confirmed me in that opinion. Accordingly, as these changes of current, involving reversal of batteries, were troublesome, and complicated the work, Captain Heaviside and I abandoned them altogether for land-wire measurements.

Cable retardation a serious quantity.

23. In cable work however the question is very different; here the retardation itself is so much increased that we can no longer afford to neglect its possible irregularities, but must take advantage of every precaution promising to eliminate their effects, while we may hope with more reason even to detect and evaluate some of the variations. Moreover, the

existing arrangements in cable offices facilitate changes of current, because instead of the dots and dashes of the Morse alphabet, jerks of the syphon to one side or other of the zero line are substituted, and these are produced by a double key the connections of which reverse the battery. It was therefore arranged that each comparison of clocks should consist of four sets of 16 signals in each direction, thus—

Precaution against variation.

Details of a comparison.

	Signals from E.	Signals from W.
1st set of signals, with currents.	+	+
2nd ,, ,,	—	—
3rd ,, ,,	+	—
4th ,, ,,	—	+

and we agreed to make three such comparisons nightly. This was afterwards reduced to two.

24. When I began observations at Aden I found it best to do the cable signalling myself, for although Mr. Neuville was available at first, there was the prospect of his leaving for Suez in the middle of the work. This happened to be practicable, because, as before noted, the observatory was within about 150 yards of the cable office, and the only objection was the loss of the third advantage claimed above (paragraph 19) for this system of comparison, *viz.*, the non-interruption of transit observations.

Bombay—Aden comparisons.

We had no means of testing the ink-arrest system completely until we actually attempted to carry it out ourselves between Bombay and Aden, when I saw immediately that it would be very difficult to work with. It has been already noted that great care is required to maintain the insulation of the ink; this was especially the case at Aden where the atmosphere was extremely damp, and I found that while the electric tension was sufficiently great to *maintain* the flow of ink, it often failed to *start* it again after interruption. The result was that great delay was experienced in getting the comparisons, interfering so seriously with my work in the observatory that, for that reason alone, I found it would be advisable to make a change if possible. Besides this, however, I was ashamed of the amount of time during which we occupied the cable, and feared an intimation that the interference with traffic was too great to be permitted. We had two nights of more or less unsuccessful struggling to obtain the comparisons at Aden, during which it generally took nearly 45 minutes to obtain any passable results, and I then began to despair of attaining anything like success with the ink-arrest process, while I did not see my way clearly to any satisfactory substitute.

Difficulties.

Weak point of the "ink-arrest" method.

That method condemned and a change considered.

25. In describing the method of comparison by longitude signals as being the first which was considered at Bombay, I mentioned that there was a difficulty in arranging for the simultaneous transmission of the signals through the cable, and to the local chronograph, and this was now the only thing that prevented my proposing the adoption of that system instead of the ink-arrest method.

Difficulty of arrangement.

As I was walking home on the second night, much disheartened and very tired (the work in the Aden climate being most harassing), the way to overcome this difficulty occurred to me, and next morning, having tested it successfully, I telegraphed to Captain Heaviside to adopt it. Fortunately the necessary alterations were very simple, and no difficulty was met with in carrying it out.

Difficulty overcome.

26. The new arrangement was as follows:—One of our ordinary polarised relays was introduced into the cable circuit between the signalling key and cable (at R), so that every signal transmitted by the cable passed through the coils and worked the armature of the relay. At first I thought that it would be necessary to reverse the connections of the relay so as to get the same armature action with both (±) currents, but it was pointed out from Bombay that, by placing the relay between the cable battery and earth (at R,), the reversal of currents passed into the cable did not affect their passage through the relay. This is shown in diagram No. 1, (plate facing page) where both positions of the relay are given, the first being in dotted lines. The signalling key (K) is double, the members being so connected with the battery that the use of one puts zinc to earth and copper to cable, giving + current, while the other does the reverse, and gives — current. In the secondary circuit of the relay, *i. e.*, the circuit made and broken alternately by the armature action, one of the chronograph pen coils (C) was included, so that the action of the armature made a signal on the local chronograph, and thus every signal transmitted by the cable was also recorded on the chronograph. It took very little time to arrange this at both stations, and it proved quite successful, removing entirely any difficulty in making the comparisons, which were now carried out as follows:—

Details of new arrangement.

Put in execution.

Each comparison consists of four sets of signals, known as A, B, C, D exchanges, each of which should contain 32 individual signals, sent alternately from each station. Changes of current are introduced systematically:—

Details of a comparison.

thus, for A exchange, current from E +, from W +
B ,, ,, ,, E —, ,, W —
C ,, ,, ,, E +, ,, W —
D ,, ,, ,, E —, ,, W +

The whole operation only occupies about eight minutes from first to last.

27. The relay was placed closed alongside of the syphon recorder, and could be cut out of the cable circuit altogether by the transposition of a contact peg from P to Q. This was always done when the cable was used for talking purposes, but its omission in no way interfered with the cable work, so that there was no risk of the relay retarding the ordinary work of the office. In this case, as before, no connection was introduced between the cable and land wires, and it will also be noted that the relay could no longer in any way interfere with the action of the syphon recorder.

Ordinary cable work not interfered with.

28. The connections of the cable for receiving and sending signals require alteration, which is done by a switch alongside of the signalling key. For our comparisons, therefore, this switch had to be moved after receiving every signal, and again after sending the return, and this was the only part of the process which gave us any trouble at first. It also interferes with the record, because, on putting the switch over after transmitting a signal there always occurs what is known as a "kick" from the condensers, which are placed between the key and earth, causing a violent disturbance of the syphon. An exact copy of the record is attached (see diagram No. 2, plate facing page), on which the transmitted signals are marked A, A, and those received B, B, the unmarked digressions being the effects of the "kick." The kick can only be traced at the distant end by a slight displacement of the zero line.

Description of the signalling and of the record produced.

29. It would be a great advantage to avoid the use of the switch, both in order to get rid of the kick and for the convenience of the signaller; and it is possible to do so by adopting a modification of the 'duplex' system of working, in which the switch is not used. I have already mentioned that when working duplex the transmitted signals are not locally recorded, but this is only absolutely true when the electric balance (the secret of the duplex system) is perfect; and when that balance is thrown out, the transmitted signals are recorded in a degree depending on the amount of the disturbance. This exactly suited our purpose, because we could disturb the balance just sufficiently to obtain well-marked local signals. We tried this in the morning (when we could generally obtain the use of the cable for protracted experiments) with excellent results, and we agreed to introduce it for the comparisons the same night. We found, however, that it was not practicable for a continuance, because the cable being almost always worked on the simplex system alterations were required if we worked by duplex, which were not under our own control, and caused delay and trouble in the office. We had therefore to content ourselves with the less perfect record of comparison obtainable with the simplex arrangement.

Improvements possible by duplex arrangement.

Tried with success, but found impracticable.

30. I may remark here that our experiments in Bombay included many of which no notice has been taken, because it was found that the objects aimed at were impracticable for the above reason, *i. e.*, because of interference with the usual arrangements of the cable offices, which it is necessary to avoid as much as possible.

Interference with cable office arrangements to be avoided.

31. All the comparisons between Bombay and Aden were signalled by Mr. Bond at Bombay, and by me at Aden. At Suez, where the observatory was a mile from the cable office, Mr. Neuville did the signalling with Mr. Bond at Aden.

Execution of comparison.

32. In the reduction of these comparisons the interpolation of the received, between transmitted, signals seemed likely at first to prove very laborious, but as the work went on, the regularity of signalling became so great, that I found it quite feasible to use a glass scale of converging lines, such as we have always used for reading the chronographic records. With such a scale the interpolation becomes very simple, the interval of B after A being read off at once in decimal parts of the tape interval A A, and converted into seconds by multiplying by the known (chronographic) time interval A A. While in England I was able to have a set of these scales made, and they have proved of the greatest service.

Reduction of comparisons.

Glass scale for reading.

33. With regard to reading off the tape records of comparisons, the question arises as to the part of each signal which should be used, and the choice lies between two, *viz.*, the first departure of the syphon from the zero line, which we have designated the "initial disturbance," and its maximum divergence, which we call the "crest." The retardation of the latter is of course much greater than that of the former, but this affords no argument in favor of either, so long as the constancy of both retardations is considered equally good. *Cæteris paribus*, the variations of the greater quantity must be more serious than those of the smaller. There seems moreover good reason for suspecting more irregularity in the retardation of the "crests," as this must surely be more dependent on the manner in which the key is used, the force with which contact is made, and the interval of time during which it is maintained, as also on the state of the batteries and condensers.

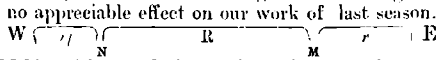
Question as to the part of the cable signal to be used.

For the above reasons I would prefer using the "initial disturbance" of the received signals, but unfortunately these are not nearly so well defined as the crests, and a much greater uncertainty of reading enters. We have therefore made a practice of reading off both, which will afford two complete sets of comparison results with different features, as to which I can only say at present, that the retardation by the crests will be about double that by the other set, while I expect the probable errors of crest results to be considerably the smaller. The exact method of combining the two remains to be decided.

First indication of local tape signal adopted.

34. The foregoing remarks apply only to the signals received through the cable (B, B,) on the tape record. Of the transmitted signals (A, A,) the first indication is always used, not only as more reliable in itself, but because it corresponds most nearly to the twin signal on the local chronograph. As a large personal equation may probably obtain in reading these tape records, its effect has been guarded against by my reading the whole set.

Combination of land wire and cable retardation.

35. There is a feature in the retardation of signals involved in the clock comparisons as we carried them out, which calls for recognition, although it can have had no appreciable effect on our work of last season. The situation 

is sketched in the diagram, showing the cable M N, with retardation R, lying between the two land wires connecting the cable office and the observatory at each end, the retardations of which are called r $r_{\prime}$. Now a signal made at M is recorded on the chronograph at E, and on the tape at N, after intervals r and R respectively, so that (R being always greater than r or $r_{\prime}$), the record at N is R—r later than that at E. Again the record at M is later than that at W by R—$r_{\prime}$. Thus it appears that we cannot use this method on the theory of equal retardation in both directions, unless we are justified in assuming $r=r_{\prime}$. As the distances between the office and our observatory were only about 3 miles at Bombay, 150 yards at Aden, and 1 mile at Suez, this assumption is safe.

Station sites, and how fixed.

37. Some notice of the points chosen for our stations during the season will be given here. Those at Madras, Bellary, Bombay, and Mangalore were the old points formerly used as longitude stations, the method of fixing which, by connection with stations of the Trigonometrical Survey, has been already described.

Aden.

At Vizagapatam a convenient site was chosen, and connected with the Trigonometrical Survey by minor triangulation with a 12-inch theodolite. At Aden Captain Heaviside observed the latitude of the station with a 10-inch theodolite, and connected the station by a small survey, for which a base line was measured, with several points of importance on the island, including the old pendulum station, and Lord Lindsay's station for his chronometrical determinations of longitude for the Transit of Venus. It was an object at Suez to adopt the same point as that used for the observation of the Transit of Venus, when the observatory was placed on the mound of earth some 40 feet high, on which the building known as the Khedive's Chalet stands. We had no precise data for the discovery of this station, but I am glad to say that Mr. Neuville hit on the exact spot, which I fixed by measurement as being 91 feet 9 inches from the south-east corner of the Chalet, and 49 feet 3 inches from a flag-staff on the mound. I afterwards found that Mr. Hunter, who was in command of the Transit of Venus party, gave these same measurements for his station as 91 feet 8 inches and 48 feet 6 inches. It was this point which had already been connected longitudinally with Greenwich.

Lord Lindsay's longitude station connected.

Transit of Venus station at Suez.

Lord Lindsay's longitude station at Suez connected.

38. There was another station used at Suez by Lord Lindsay's Transit of Venus party, for the purpose of a determination of differential longitude with Aden, where the station adopted has been already alluded to. The point at Suez was close to the cable office, and was connected with our station by means of a traverse carried out with theodolite and tape.

Bad foundation at Suez.

39. Our station at Suez had one objection, arising from the fact of the mound having originally been artificial, though I believe of somewhat ancient date, in consequence of which the foundation of the piers was faulty. This showed itself distinctly in the levelling, which proved that settlement was going on from day to day throughout the observations, and I am sorry to say that the azimuth observations show the same, which affords reason to fear that our results may have somewhat suffered from this cause.

Narrative of the season completed.

40. Having now given a narrative of the season's work, and endeavoured to explain whatever of novelty has entered into the operations, on account of their extension by sub-marine cables, I shall turn to a few points of interest in the observations generally.

Reductions of 1875-76.

41. At the beginning of this report, I alluded to a change in the mode of reducing the observations of 1875-76, which was rendered necessary by the discovery of an interesting feature in our personal equation of star transits.

Machine for measuring personal equation.

When our reductions were approaching completion last year I received a pamphlet, from the United States Hydrographic Office, on electro-longitude operations and personal equation, in which reference was made to a machine for measuring personal equations. This directed my attention to a method for measuring absolute personal equation by means of the chronograph, which I had myself devised some years previously, but for various reasons had never carried out practically; and certainly it could not have been relied upon to give results for comparison with the equations obtaining in star observations, because of the difference of the conditions. This contrivance (somewhat modified on account of the alterations since made in our apparatus) Captain Heaviside and I now proceeded to use, with the following interesting result, *viz.*, that we found our relative equations to vary according as we observed an object travelling from right to left, or from left to right.

Difference in equation according to direction of motion of object observed.

Now, as we take all our transits in a sitting posture by means of an oblique eye-piece, it follows that stars north and south of the zenith cross the wires from right to left, and left to right respectively, and therefore, according to the discovery just made, the observations of such stars should be combined with different personal equations.

42. A re-discussion of all divided transits, taken for relative personal equation throughout the season, was then gone through with the stars divided into two groups north and south of the zenith, and the result strikingly confirmed that indicated by the absolute equations. The original equation for all stars having been C — H = + $\overset{s.}{0064}$ ± $\overset{s.}{\cdot 0057}$, we now found—

New reduction of personal equation for the season 1875-76.

By north zenith stars C — H = + $\overset{s.}{0{\cdot}102}$ ± $\overset{s.}{\cdot 0087}$.
And by south zenith stars C — H = + 0·041 ± ·0034.

The portion of the reductions combining the star observations by both of us was then re-computed with the two new equations instead of the old one, and it is very satisfactory to note that a marked improvement in the general accordance of the final results was obtained. In carrying this out some difficulties arose from the fact, that when a star is very close to, the zenith it may be equally conveniently observed either as a north or south star, whence in many cases it was doubtful how an observation should be treated.

Re-computation, with improvement in results.

43. We have fully recognized this feature of personal equation during last season's work now under reduction, carefully noting at the time on which aspect a zenith star was observed. We also, when possible, adopted a mean zenith for the two ends of an arc,—say in declination 15°15′ for Madras and Vizagapatam, in latitude 13°,and 17° 30′ respectively—so that, the southern observer treating all stars south of this mean zenith as south stars, while he at the north station treated all these north of it as north stars, all transits were taken with the same aspect at both stations. Besides this, each observer made a practice of taking several stars close to his own zenith on both aspects, *i. e.*, he observed them over the first ten wires as north stars, and then turning round took the last ten wires as for a south star, or *vice versâ*, and in this way each has obtained a good value of his absolute equation between north and south stars for each station. This we call the " N—S" equation.

Precautions introduced in season 1876-77.

Each observer's absolute equation of north and south stars, known as the N—S equation.

44. The results for our combined observations for relative personal equation by divided transits (as before) which were carried out on 15th, 18th and 19th December, and on 4th, 5th, 7th, and 9th April, with both instruments, are also carefully grouped for stars of north or south aspect, giving a relative equation for each. These we call " C_N—H_N" , " C_S—H_S" respectively. As we cannot make choice of one of these as of more value than the other, the method in which we propose treating the whole subject is this.

Relative personal equations by north and south stars known as C_N—H_N and C_S—H_S.

All the results of each observer will be treated as obtained from north stars, by applying his absolute N—S equation to his south stars, and these will be combined by means of the relative equation C_N—H_N obtained from north stars. Again, all individual results will be reduced to south stars and combined by the south star equation C_S—H_S, and finally a mean of the two results will be taken.

Application.

It may be as well to note that this N—S equation is attributed wholly to the fact of the stars crossing the field in opposite directions. Difference in the rate of motion has very likely a secondary effect, but on that point I can produce no evidence.

45. Our personal equation determination of this season is not quite so satisfactory as that for 1875-76, as in the first place we had not so many opportunities of carrying it out, and in the second the results obtained are not so accordant. After all, however, the whole thing cannot rank much above a rough approximation when carried over such long periods, with so many changes of condition affecting the observers. For instance, it is easy to suppose that a week of sea-sickness will seriously affect an observer's personal equation. This must always remain the weak point of observations for differences of Longitude.

Uncertainty of personal equation.

46. Besides the personal equation of transits, there is the probable equation in reading off the chronograph sheets to be guarded against. Last year this was done by taking care that the same person should read the records at both stations of any particular piece of work, but that could not be arranged this season, because each observer was able to transcribe a large part of his own

Personal equation of reading records.

records in the field. This equation has therefore been determined by comparing transcripts of the same record by both observers. It amounts to about $0^s{\cdot}01$.

47. The determination of the azimuthal deviations of the transit instruments has given more trouble than usual during last season's observations, on account of the prevalence of clouds.

Azimuth observations.

To supplement star observations, Captain Heaviside introduced at Vizagapatam a distant referring lamp, about 4 miles from the Observatory, and I strongly recommend the use of such a lamp whenever practicable, which however is not often the case.

Distant referring lamp at Vizagapatam.

At Aden, where I had great difficulty in obtaining observations of either circumpolar or comparative azimuth stars (see last report, Art. 24), I put in practice a contrivance which had occurred to me for using a referring lamp at a comparatively short distance. About 500 yards was the utmost available at Aden, and at this distance a mark viewed through a powerful telescope has so much parallax as to be quite unfit for observation.

Not practicable at Aden.

48. I had a tin cap made with a small opening of about ¾ inch diameter, and when this was affixed in front of the object glass, a very good image of the referring lamp became visible on the plane of the wires, and therefore without parallax.

Contrivance for using a near referring lamp.

The explanation of this is as follows. If a small portion only of a lens of long focus be used, the convergence of rays is so slight, that there is a considerable range on either side of the true focus, within which a fairly distinct image will be formed on a screen. In the present case the screen is imaginary, but its position is defined by the focus of the eye-piece, which is, of course, adjusted to be coincident with the plane of the wires.

The relative positions of the referring lamp and telescope being constant, the position of the image of the former, seen on the wires of the latter, will vary according to the position of the small opening in the tin cap with reference to the object glass, as is shewn in diagram No. 3, (plate facing page.)

Here O O is the plane of the object glass and F F that of the wires, *i. e.*, of solar focus; and f is the focus of the near referring lamp. A B C D and a b c d are, respectively, transverse sections of the object glass in the plane O O, and of the cone of rays, of which the object glass is the base and f the apex, in the plane F F.

Now, if the referring lamp be observed through the small opening placed at A, B, C, or D (the telescope remaining fixed), its image will be seen at a, b, c, or d respectively; and the closer the referring lamp is to the telescope, the greater will be the distances of a, b, c, or d apart.

49. The collimator being directly in the line between the telescope and referring lamp, in order to observe the latter (without moving the collimator or seeing through it), it was necessary to place the small opening opposite the extreme edge of the object glass, as at D, and thus the referring lamp was observed as at d, although really placed on the prolongation of the axis of collimation R f.

Method of observing it.

This is a matter of no consequence, so long as the tin cap is always put on in exactly the same position, because the referring lamp readings are only treated differentially from night to night. Thus, if an absolute value of deviation is obtained from star observations on any one night, and compared with a reading of the referring lamp on that night, then by comparing the latter with referring lamp readings on any other night, a value of deviation can be deduced. If it is required to combine readings of the referring lamp taken with telescope I. P. E. with another set taken I. P. W., care must be taken when reversing the telescope to obtain the following observations: (1) a reading of the referring lamp with the opening in its old position; (2) a reading of the collimator with the whole object glass before reversal: again, after reversal, (3) a reading of the collimator with whole object glass; and (4) a reading of the referring lamp with the opening in its new position.

The readings of the collimator (2) and (3) show any change of azimuth which may have occurred in the process of reversal, and this, combined with the difference between the readings (1) and (4), gives the quantity, which must be applied to a set of readings taken after reversal, in order to make them comparable with those taken before. The difference of the collimated readings of the telescope micrometer in the two positions I. P. E., I. P. W., must not be lost sight of in carrying out this process. It may be added, that the observation of azimuth being in view, A, C (or top and bottom) are the worst parts of the object glass to use, while B, D (at the sides) are the best, because errors of position (of the tin cap) in these parts give respectively maxima and minima horizontal displacements in the image observed.

Nature of stars observed.
Longitude stars only for Indian arcs.

50. On the land lines measured, we made use, as before, of longitude stars only, *i. e.*, stars selected without any exact knowledge of their right ascensions and observed at both stations.

For the Aden—Bombay measurement this system was not wholly convenient on account of the great difference in longitude, because it is, of course, advisable that the clock comparisons should be taken as nearly as may be at the mean time of star observations, which is impossible when the western observer has to wait two hours for the set of stars taken by his colleague at the east station. We, therefore, adopted a combination of longitude stars and clock stars, according to which each observer determined his own clock error by well-known stars, while a small group of longitude stars was also taken by both. Between Aden and Suez the difference of time is only 49 minutes, but here, on the other hand, there is nearly 20° difference of latitude, so that the same set of stars would have a very northerly average position at Aden and the reverse at Suez, which is objectionable on account of deviation errors. For this reason it was considered best to confine ourselves to clock stars.

Combination of clock and longitude stars for Bombay—Aden.

Clock stars only for Aden—Suez.

51. Between Bombay and Aden we only used the new cable for clock comparisons, because a fault which at that time existed in the older cable made it difficult to work through, and unsuitable for our purpose. Between Aden and Suez we used the two cables nearly equally.

Which cable used.

Personal acknowledgments.

Mr. Pogson.

55. Mr. Pogson, Government Astronomer at Madras, gave me, as usual, every facility for carrying out my work at his Observatory.

Mr. F. Chambers.

Mr. F. Chambers, who was acting for his brother, Mr. C. Chambers, in charge of the Observatory at Colaba, was also most obliging and anxious to meet my wishes on all points.

56. I have, as usual, to acknowledge the greatest courtesy in meeting our wants from all the officers of the Telegraph Department concerned. In the matter of electro-longitude work, the Great Trigonometrical Survey owes much gratitude to the members of the sister department, from their late lamented chief, Colonel Robinson, R. E., downwards, for hearty co-operation and assistance.

Officers of the Indian Telegraph Department.

57. When we began the cable operations, the Directors of the Eastern Telegraph Company were good enough to allow us the free use of the lines for our observations, and also gave instructions that we should be allowed every facility, provided the traffic were not impeded. These instructions were most liberally interpreted, and the amount of work which we were allowed to do with the cables often surprised me. The fact of the duplication of the cable having just been completed between Suez and Bombay was, of course, a great advantage to us in this respect. We met with the greatest attention in all the offices, *viz.*, at Bombay, Aden and Suez; everything was done to assist us, and much interest seemed to be taken in our progress. To Messrs. Smith, Stacey and Tuck, Superintendents at Bombay, Aden and Suez, respectively, our thanks are particularly due, most especially to the first-named, in whose office the preliminary experiments were carried out, and the delays at first starting experienced.

Officials of the Eastern Telegraph Company.

58. I am also very grateful to Dr. Muirhead, who was in Bombay when we first entered on the work, in which he took a lively interest, and was always ready with advice or assistance in making experiments. Dr. Muirhead was not officially connected with the cable, but being the inventor of the artificial cable—a set of condensers ranged on shelves in the office, so constructed as to give an exact imitation of the real cable as regards resistance, leakage, &c., by which the balance is obtained for duplex working—he came to Bombay to see it brought into use with the new Bombay—Suez cable, the laying of which was only completed last March.

Dr. Muirhead.

59. The British Consul at Suez, Mr. West, was very obliging, and assisted us in many ways, particularly in getting us permission to use the site we desired, and to build upon it; in procuring workmen, and also in passing our instruments through the Custom-house without delay.

Mr. West, H. B. M. Consul at Suez.

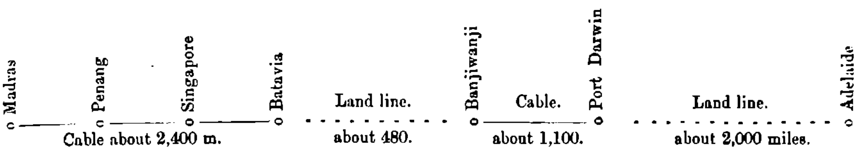
60. When in England on privilege leave I took the opportunity of visiting Greenwich, in order to describe what we had done to Sir George Airy. I took with me specimens of the chronographic and cable tape records, and explained our system of comparing clocks. Sir George showed the greatest interest in the matter, and was good enough to express great admiration of our records.

Visit to Sir George Airy at Greenwich.

61. I then ventured to express my opinion of the desirability of extending these operations, by which India is now connected with Greenwich, to the Australian colonies, a question into which the Astronomer Royal warmly entered, and at his request I afterwards furnished sketch estimates of the expense which would be incurred if such operations were at any time carried out.

Question of Australasian longitudes.

I eventually pointed out that, by the system which we had adopted, extended as described in paragraph 35 of this report, but somewhat modified and complicated because the syphon recorder would not be available, it might be hoped to connect Madras and Adelaide with only one astronomical station between, as shewn in the diagram—



Direct signalling would probably be practicable through the cables joined up between Madras and Batavia, so that the measurement might be made in one operation with astronomical stations at the two ends. Then the section Batavia to Adelaide might be measured with only signallers at the ends of the intermediate cable (as described in paragraph 35).

It is true that the land wire of about 2,000 miles across Australia might be a formidable section to work through, though, considering the dryness of the climate, I have but little doubt that it would be practicable. This point, however, does not affect the question, as it may be taken for granted that no Astronomer will ever visit the centre of Australia (in our time at least), in order to provide an intermediate station of observation on the telegraph line, and if the distance should prove too great for direct signalling, the work will be done, if ever, by means of introducing relays. This could be carried out just as well on the system now under discussion as with an astronomical station at Port Darwin, only one would advocate the precaution of introducing, between Banjiwanji and Batavia, as many relays as might be used in crossing Australia, in order to obtain nearly equal retardations on these two land lines.

Extract from Supplementary Narrative Report, dated 16th January 1878, of Captain (now Major) W. M. Campbell, R.E.

Since writing my Narrative Report, the reductions of last season's work have been completed and the results arrived at, which I have now the pleasure of submitting, and I shall take the opportunity of making a few additional remarks which have suggested themselves during the progress of the computations.

Clock comparison by cable.

As regards clock comparisons and the transcript of two sets of signals, *viz.*, those afforded by the "initial disturbance" of the syphon, and by the "crests" of the waves, the results have borne out the expectations expressed in the body of my report. The crests give results with smaller probable errors, but their value of retardation, while about twice as great as that by initials, is also not nearly so constant.

Wave or syphon time.

A feature has been found which was not thought of at the beginning of the work, *viz.*, a constant difference between the two ends of the cable, in the interval of time between initial and maximum (or crest) disturbance.

This we have called the "wave or syphon time," the alternative designation being employed because of the doubt existing as to the exact nature of the interval, which seems to arise from a combination of two causes—

Causes.

(1).—A cable requires time to take up its maximum charge, which may be called the "wave time;" and this time is dependent not only on the state of the cable, but on that of the batteries and condensers, and on the mode of using the key.

(2).—According to the adjustment of the syphon, the same current from the cable will produce a greater or less disturbance, and the interval between initial and crest effects on this account is called "syphon time." This interval will depend on the state of the batteries of the electro-magnet, of the syphon-recorder, and on the suspension of the syphon itself.

Effects.

It need hardly be remarked that the different values of this interval at the two stations is an important matter. If it arises wholly from wave time, the initials of signals are probably least, if at all, affected, and would therefore give the best results. If, on the other hand, it were due to the syphon time only, it might be considered that the syphon making the greater excursions would start sooner, and continue the movement later, *i.e.*, that the initial movement of the one would be nearly as much before that of the other, as the crest would be later; and in this case the mean of the two would probably give a result nearly cleared of the effects of the difference.

Treatments of results.

I am not prepared to advance a decided opinion on the best treatment. I believe that the wave time is the more probable source of the difference, and that, therefore, the initial results are to be preferred. I held this opinion from the beginning, but the idea of syphon time did not occur till later, and it now seems to me that it is probably to a certain extent responsible, particularly as a slight inspection of the record shows a marked relation between the difference in the heights of the waves, and the difference of the wave or syphon time, at the two stations. On the other hand, there is the fact, that when the cable was changed in the measurement Aden—Suez, the sign of the wave time difference was reversed, although the same recorders were used as before.

The difference of clocks has been taken out in two ways—(1) by using the initial signals only, and (2) by taking a mean between the initial and crest results.

The difference of longitude has, however, been deduced only from the "initial disturbances." This is somewhat arbitrary, and it would be satisfactory to obtain an opinion as to the best treatment, by an electrician who should have access to the results of all battery and cable tests, taken while our work was in progress.

Such an opinion, so far as I have been able to get it, *viz.*, from Mr. Smith, Superintendent of the Eastern Telegraph Company in Bombay, who, however, was not so thoroughly acquainted with the facts as desirable, is in favor of the course adopted.

In the present case it is after all more a matter of curiosity than importance, the quantities being small, and their signs such that they nearly cancel in the whole measurement Bombay—Suez.

Recommendation for guidance in future.

I should certainly not recommend both initials and crests being read in future, but initials only, while a few crests might also be read in order to compare the wave times. Improvements in signalling would probably make the initials as good as the crests for reading, and the saving in time would be great, as the transcription of these tapes is very laborious.

Results obtained.

Results of the season's work

Of the three land measurements executed, two, *viz.*, Vizagapatam—Madras, and Vizagapatam—Bellary, combined with Madras—Bellary, measured in 1875-76, complete a circuit, the closing error of which is $0^s \cdot 041 \pm 0^s \cdot 018$. This is disappointing, inasmuch as it is considerably greater than any similar error of the work done in 1875-76, but I cannot consider it surprisingly large. Unfavourable weather may have something to say to it, cloudiness being certainly likely to interfere with even the observations obtained. For a plausible explanation, however, we need not look farther than the uncertainties found to exist in our personal equation, as the difference between its values by the determinations preceding and following these measurements amounted to $0^s \cdot 053$ and $0^s \cdot 045$ for $C_N - H_N$ and $C_S - H_S$ respectively.

It is true that the equation affected both these arcs with the same sign, but the question is one of constancy, and the uncertainty seems quite sufficient to account for discrepancies of $0^s \cdot 02$ or $0^s \cdot 03$. Indeed, it may probably be assumed that any agreement within $0^s \cdot 03$ is more or less fortuitous.

The arc Mangalore—Bombay, combined with Madras—Bombay, measured in 1875-76, and Madras—Mangalore of 1872-73, affords another circuit, the closing error of which amounts to no less than $0^s \cdot 354$, the measurement of 1872-73 being in defect.

This is contrary to my expectations, as I hoped to find a close agreement, proving that the effect of the faults of No. 2 telescope during 1872-73 had been nearly eliminated in the whole measurement. I can only regret now that I was rash enough to make any prediction regarding the results obtained from that telescope in the condition it was in at the time.

Final longitude of Madras.

The longitude of the Madras Observatory, which results from combining our measurements between Madras and Suez, with the longitude of Suez supplied by Sir G. Airy, is $5^h\ 20^m\ 59^s.416$, being $2^s \cdot 116$ in excess of the value hitherto adopted, as given in the Nautical Almanac.

The effect of the season's operations is therefore to remove India, theoretically, about 2,000 feet farther from England!

Tables of results.

Tables of our results, with explanations, are appended to this report.

In these are included the elements of certain points fixed by triangulation at Aden, the data of origin being our longitude determination of this year, and the latitude observed by Captain Heaviside.

The position (by our traverse) of the point at Suez used for determinations of longitude, in connection with Lord Lindsay's transit of Venus Expedition of 1874, is also given.

Personal equation the limit to accuracy.

The uncertainties of personal equation must, I fear, always remain the great bar to obtaining in longitude observations, a degree of accuracy which will compare favourably with that arrived at in the best determinations of latitude, but there is room for improvement, and I hope the next series of observations entered upon will find us better armed against this our worst enemy.

Determination open to improvement.

Mathematical Instrument Department.

There has always been a weak point in the difference of power used with the two telescopes, owing to that of one eye-piece being about double that of the other. We have done what we could to obviate this by determining personal equation equally with both instruments, but this could, of course, only be looked on as a rough remedy. A new eye-piece has now been made in the Mathematical Instrument Department, Calcutta, of the same power as the best of the original pair, and this should bring the circumstances of personal equation, as determined, much more in accord with those exsting during actual observations, and it may be hoped will effect a corresponding improvement in results.

Another minor point has been attended to by the addition of a few ordinary spectacle lenses, sliding loosely in a cap to be put on the eye-piece, so as to allow of the same focus of the eye-piece being used for two different sighted observers when taking divided transits, one observing with the spectacle lens and the other without. The focus of the eye-piece cannot be changed while taking such observations, and we have hitherto only been able to work in that way because the observers happened to have nearly the same eye-sight.

The great desideratum, however, is some contrivance for measuring absolute personal equation satisfactorily.

I have designed a simple instrument for this purpose, which I hope will answer the chief objects in view, *viz.*, to afford a close imitation of a real star transit, and to be easily brought into use during any available interval of a few minutes' duration. A detailed description cannot be given here; suffice it to say, that an imitation star will automatically record on the chronograph its transit across a series of wires, while the observer records the same events in the usual way.

This instrument is now being constructed in the Mathematical Instrument Department, Calcutta, and I propose calling it an "idiometer," for which name I am indebted to Major Herschel, R.E.

Abstract of Final Results of 1875-76.

CIRCUIT I.

			m s s
ΔL	Bolarum—Bombay		22:48·849±·0059
„	Bellary—Bombay		16:26·959±·0114
„	Bolarum—Bellary	Deduced	6:21·890±·0128
		Observed	6:21·883±·0121
		Difference	0·007±·0176

CIRCUIT II.

ΔL	Madras—Bolarum		6:54·692±·0109
„	Madras—Bellary		13:16·563±·0112
„	Bolarum—Bellary	Deduced	6:21·871±·0156
		Observed	6:21·883±·0121
		Difference	0·012±·0198

CIRCUITS I AND II COMBINED.

ΔL	Bolarum—Bombay	22:48·849±·0059
„	Madras—Bolarum	6:54·692±·0109
„	(1) Madras—Bombay	29:43·541±·0124
„	Bellary—Bombay	16:26·959±·0114
„	Madras—Bellary	13:16·563±·0112
„	(2) Madras—Bombay	29:43·522±·0160
	Difference between (1) and (2)	0·019±·0202
	Mean of (1) and (2)	29:43·534±·0101

CIRCUIT III, 1872-73 and 1875-76.

ΔL	Madras—Bellary	13:16·563±·0112
„	Bangalore—Bellary	2:37·364±·0126
„	Madras—Bangalore deduced	10:39·199±·0169
„	Do. measured in 1873	10:39·043±·0102
	Difference	0·156±·0197

Explanation of terms used in accompanying statements.

$C_N - C_S$: $H_N - H_S$, respectively, indicate Captain Campbell's and Captain Heaviside's absolute equations between the observations of stars of north and south aspect, (see report, para. 43).

$C_N - H_N$: $C_S - H_S$, are similarly the relative equations for combining the observations by both officers of north and south aspect stars (para. 44).

ΔL is generally, "difference of longitude."

ΔL_N : ΔL_S, are values of ΔL deduced from observations of all stars; where observation of stars of south aspect are reduced to north aspect, by the equations $C_N - C_S$ $H_N - H_S$, for ΔL_N, and *vice versâ* for ΔL_S (see report, para. 44).

$C_r - H_r$, is the transcribing equation (para. 46).

ρ is the retardation of signals between stations on land lines.

Deduction of final values of Captains Campbell and Heaviside's relative personal equations, $C_N - H_N$, & $C_S - H_S$.

By Stars of North Aspect.					By Stars of South Aspect.		
Date.	Telescope.	Mean Value $C_N - H_N$ (a)	Weight (w)	$(a)\times(w)$	Mean value $C_S - H_S$ (a)	Weight (w)	$(a)\times(w)$
1876.							
December 15th ...	No. 1	s +0·14	38	4·712	s +0·057	48	2·736
„ 18th ...	Ditto.	·125	56	7·000	·069	38	2·622
„ 19th ...	No. 2	·150	64	9·600	·071	28	1·988
General Mean $= \frac{\Sigma a\,b.}{\Sigma\ w} =$ +0·135 s							s +0·064
1877.							
April 4th	No. 2	+0·085	9	+0·765	—0·028	23	—0·644
„ 5th	Ditto	·025	93	2·139	·004	222	·888
„ 7th	No. 1	052	65	3·380	·025	35	·875
„ 9th	Ditto	— ·027	23	—0·621	·042	303	12·726
General Mean $= \frac{\Sigma a\,b}{\Sigma\ w} =$ + 0·030 s							s —0·026

Final values adopted.

For land measurements, carried out between December 1876 and April 1877, means of the above are adopted, *viz.*:—

$$C_N - H_N = +\overset{s}{0}{\cdot}083,\quad C_S - H_S = +\overset{s}{0}{\cdot}019.$$

For cable measurements, executed subsequent to April 9th, 1877, the last determined values are adopted, *viz.*:—

$$C_N - H_N = +\overset{s}{0}{\cdot}030,\quad C_S - H_S = -\overset{s}{0}{\cdot}026.$$

The values of each observer's N—S equation are as below:—

for arc	Vizagapatam	—Madras	$H_N - H_S =$	+ 0·015, s	$C_N - C_S =$	+ 0·077. s
„	„	—Bellary	„	+ 0·033,	„	+ 0·055.
„	Mangalore	—Bombay	„	+ 0·026,	„	+ 0·046.
„	Bombay	—Aden	„	+ 0·006,	„	+ 0·074.
„	Aden	—Suez	„	+ 0·022,	„	+ 0·058.

Abstract of resulting values of difference of longitude, Season 1876-77.

Details for land wire measurements.	Vizagapatam—Madras.	Vizagapatam—Bellary.	Mangalore—Bombay.
By E. Clock.			
$\Delta L_N - \rho$	m s 12: 9·853	m s 25: 26·410	m s 8 : 7·395
$\Delta L_S - \rho$	9·791	26·388	7·375
By W. Clock.			
$\Delta L_N + \rho$	12: 9·902	25: 26·491	8: 7·464
$\Delta L_S + \rho$	9·840	26·469	7·444
Whence ΔL_N	12: 9·878	25: 26·451	8 : 7·430
$C_N - H_N$	— ·083	— ·083	—·083
ΔL	12:9·795	25: 26·368	8: 7·347
Again, ΔL_S	12: 9·815	25: 26·428	8: 7·409
$C_S - H_S$	— ·019	— ·019	—·019
ΔL	12: 9·796	25: 26·409	8: 7·390
Mean ΔL	12: 9·796	25: 26·389	8: 7·369
$C_r - H_r$	— ·011	·000	·000
Final ΔL	12: 9·785 ±0·012	25: 26·389 ± 0·008	8: 7·369 ±0·013
Also ρ	+0·0250	+0·0405	+0·0345
Length of wire used	500 miles.	897 miles.	950 miles.

Details for cable measurements.	Bombay—Aden.		Aden—Suez.	
	1 h —51m		0h —49m	
By clock stars	ΔL_N=19·972 (s)	ΔL_S=19·904 (s)	ΔL_N=42·661 (s)	ΔL_S=42·625 (s)
$C_N - H_N$, or $C_S - H_S$ ...	—·030	+·026	—·030	+·026
$C_r - H_r$	+·011	+·011	·000	·000
Corrected resulting values ...	ΔL=19·953	ΔL=19·941	ΔL =42·631	ΔL =42·651
Mean ...	ΔL=19·947+0·026		ΔL=42·641±0·015	
By longitude stars	ΔL =20·021	ΔL =19·953	ΔL =42·707	ΔL = 42·671
$C_N - H_N$, or $C_S - H_S$	—·030	+·026	—·030	+·026
$C_r - H_r$	+·011	+·011	·000	·000
Corrected resulting values ...	ΔL_n =20·002	ΔL_s =19·990	ΔL_N =42·677	ΔL_S =42·697
Mean ...	ΔL=19·996±0·016		Δ L=42·687±0·022	
Final value of ΔL	s m s s 1 : 51 : 19·983±·015		h m s s 0 : 49 : 42·656±·013	

Abstract of Results, 1876-77.

			m s s
△L	Vizagapatam—Madras	... ...	12: 9·785±0·012
,,	Vizagapatam—Bellary	... ...	25:26·389±0·008
,,	Madras—Bellary	Deduced ...	13:16·604±0·014
		Observed 1875-76 ...	13:16·563±0·011
		Difference ...	0·041±0·018

			m s s
△L	Mangalore—Bombay	... ...	8: 7·369±0·013
,,	Madras—Bombay, observed 1875-76	...	29:43·534±0·010
,,	Madras—Mangalore	Deduced ...	21:36·165±0·016
		Observed 1872-73 ...	21:35·811±0·014
		Difference ...	0·354±0·021

Results of Seasons 1875-76 and 1876-77, combined to afford final value of △L Madras—Bombay.

The diagram shows the measured arcs available for the deduction, and the quantities are as below.

			m s
A	Measured in 1875-76	=	16:26·959'±0·011'
	C = 22:48·849±·006 (m s s)		
	D = 6:21·883±·012		
A	=(C—D) deduced ,,	=	16:26·966±0·013
B	Measured	=	13:16·563±0·011
	E = 6:54·692±·011		
	D = 6:21·883±·012		
B	=(E+D) deduced ,,	=	13: 16·575±0·016
	F = 25:26·389±·008		
	G = 12: 9·785±·012		
B	=(F—G) deduced 1876-7	=	13: 16·604±0·014

Whence, using combination weights.

△L Madras—Bellary, Mean A = 16:26·962±0·009 (m s s)

△L Bellary—Bombay ,, B = 13:16·578±0·008

△L Madras—Bombay, A + B = 29:43·540±0·012 (m s s)

The measurement D enters twice in the above deduction, which therefore is not quite rigorous.

Resulting value of the longitude of Madras.

	h. m. s.	
Longitude of Mokattam, East of Greenwich	2 : 5 : 6·320	Supplied by Sir G. Airy.
" " Suez, " " Mokattam	0 : 5 : 6·917	
" " Aden " " Suez	0 : 49 : 42·656	G. T. Survey, 1876-77.
" " Bombay " " Aden	1 : 51 : 19·983	
" " Madras " " Bombay	0 : 29 : 43·540	G. T. Survey, 1875-76-77.
Longitude of Madras east of Greenwich	5 : 20 : 59·416	

The longitude of Madras as given in the Nautical Almanac = 5 h. : 20 m. : 57·3 s.

Aden Triangulation.

	Latitude.	Longitude.
Elements of the Points.		
Longitude station	12° 46′ 27″·00	44° 58′ 58″·40
Lord Lindsay's station*	12 47 14·70	44 59 11·56
Intersected Points.		
Sham Sham flagstaff	12 46 30·30	45 0 41·86
Residency "	12 46 45·11	44 58 29·16
Saluting Pier "	12 47 20·88	44 59 58·49
Light-ship (outer)	12 47 20·45	44 58 18·52
Light-house (Marshag)	12 45 43·02	45 3 19·74
Renny's flagstaff	12 47 3·53	44 58 42·69

* The outer wall of the room in which the pendulums were swung by Captain Heaviside in 1873, is 88 feet distant from this station, in a direction 27° 10′ west of south.

At Suez.

The pillars used for the longitude observations in connection with Lord Lindsay's Transit of Venus expedition of 1874, were found by traverse to be 0·025 s. west and 23″ south of our longitude station. Whence their—

Longitude = 2 h. : 10 m. : 13·212 s., and latitude (approximate) 29° 57′ 56.″

At Colaba, Bombay.

The transit instrument of the Colaba Observatory was found by measurement to be 0·134 s. to the west of our longitude station. Whence—

Longitude of Colaba Observatory transit instrument = 4 h. : 51 m. : 15·742 s. east of Greenwich.

Mean results regarding the retardation of signals through the cables.

The quantities tabulated are halves of the double retardations to and fro deduced from the clock comparisons.	Part of signal observed.	RETARDATION ACCORDING TO CURRENT AT EACH (EAST OR WEST) STATION. E. + W. +	E. − W. −	E. + W. −	E. − W. +
BOMBAY—ADEN		s	s	s	s
(New cable) length 2172 miles	Initial ...	0·285	0·273	0·282	0·286
	Crest ..	0·533	0·482	0·505	0·549
ADEN—SUEZ					
Old cable, 1685 miles	Initial ...	0·306	0·294	0·299	0·286
	Crest ...	0·557	0·533	0·547	0·541
New cable, 1683 miles	Initial ...	0·266	0·270	0·277	0·258
	Crest ...	0·517	0·499	0·499	0·516

Wave or syphon times.

Arcs and cables.	VALUES AT East.	VALUES AT West.	Difference E.—W.	Limits between which the differences vary.		N. of values of each sign. +	N. of values of each sign. −
BOMBAY—ADEN	s.	s.	s.	s.	s.		
New cable	0·256	0·209	+0·047	+·185	−·036	53	15
Old cable	0·230	0·266	−0·036	−·235	+·008	1	27
ADEN—SUEZ							
New cable	0·240	0·241	−0·001	−·051	+·098	10	10

Extract from the Narrative Report, dated 16th January 1878, of J. B. N. Hennessey, Esq., M.A., in charge Computing Office.

On Mr. Cole's departure on furlough, 21st March 1876, the Calculating and Printing branches of the Computing Office were placed under Major Herschel, and the Drawing and Photozincographing branches under Captain Thuillier. This arrangement continued in effect until the return from furlough of Colonel Walker. Shortly after, I was directed to resume charge of the Office in all its four branches: Captain Thuillier then reverted to other duties; but Major Herschel continued to render aid in the supervision of the Calculating and Printing branches until the reduction of the North-East Quadrilateral was completed.

Calculating branch.

6. The following cost-table of work done in the Calculating branch is similar to the one exhibited last year; it differs from its predecessor in that, the number of classes of work has been reduced, by suitable grouping of the former classes, from 15 to 10:—

Cost-table in Rupees.

CLASSES.	November.	December.	January.	February.	March.	April.	May.	June.	July.	August.	September.	Average per cent.
1. Records, Library ...	19	24	192	214	132	209	104	89	115	66	68	5
2. Computations ...	439	514	505	464	284	213	389	426	528	259	246	18
3. Accounts, returns, correspondence ...	151	132	161	280	206	342	265	304	312	517	299	13
4. Supply	107	68	68	66	75	67	51	30	58	63	57	3
5. Press copy	434	323	199	170	138	283	419	532	323	345	449	16
6. Press proofs ...	348	263	168	355	409	290	409	402	465	458	467	17
7. Charts	159	129	33	10	115	63	27	9	0	0	51	2½
8. Stations	178	58	57	121	61	35	71	41	90	18	69	3½
9. Leave, Holiday ...	146	558	670	323	419	370	150	45	39	132	202	13
10. Meteorology, Miscellaneous	146	58	74	124	188	255	242	249	197	269	225	9
TOTALS ...	2,127	2,127	2,127	2,127	2,127	2,127	2,127	2,127	2,127	2,127	2,127	1,00

DIAGRAM TO ILLUSTRATE REPORT ON LONGITUDE OPERATIONS.

by Major W.M. Campbell, R.E.,

Fig. 1

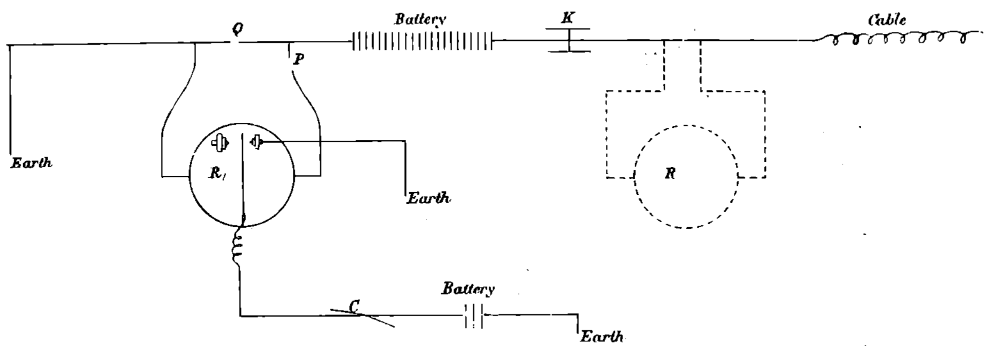


Fig. 2

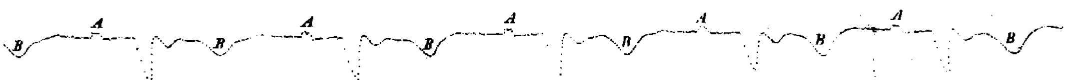
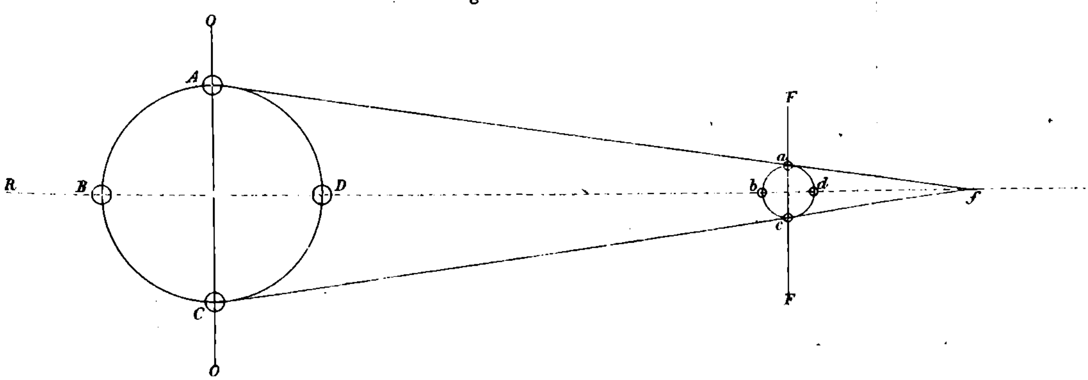


Fig. 3



7. The following particulars are due to the classes named in the foregoing:—

Calculating branch. Particulars of work.

(1). *Records, Library.*—The crowded state of the rooms available compelled the adoption of contrivances for affording all practicable relief. Every year brings a sensible accession to our field records, as each executive officer makes his annual deposit; to this, add the considerable quantity of printed matter, amounting, in the 11 months under review, to no less than 3,35,000 prints, and some idea will be formed of the space required for stowing away the documents, so that they shall be safe and accessible. The simultaneous reduction of the North-West and South-East Quadrilaterals afforded an opportunity for packing away their original records; this has been done in convenient racks, after suitable paging, indexing, &c.; and it is further intended to roughly bind these papers in course of time.

8. *Clause 2.*—Computations—

N. E. Q.—Reduction taken up at elimination from 39th equation, and concluded.
S. E. Q.—Reduction of South Páresnáth and South Malúncha Series begun and concluded.
N. W. Q.—Reduction of Jodhpur Series carried as far as computation of co-efficients of the errors Y, Z.
S. W. Q.—Data collected (in part) for investigation of final weights.

Principal Triangulation in general (in duplicate).

Weights, computed	7
Spherical excesses, computed	42
Reduction of simple figures, computed or corrected	6
„ of compound „ „	5
Triangles, computed or corrected	1,464
„ arbitrary corrections applied in -	100
Latitudes, longitudes and azimuths, computed (single deductions) ...	164
„ „ „ „ (2nd deductions)	624
„ „ „ corrected „	71
„ „ „ computed (3rd deductions)... ...	84
Heights, corrected and adjusted	73
Azimuths (astronomical), computed	3
„ „ partly computed	32
Non-circuit azimuths, computed or examined	1,912
Auxiliary figures, computed	64

Secondary triangulation in general (in duplicate).

Traverses, computed	1
Triangles, computed and adjusted	126
Latitudes, longitudes and azimuths, computed or corrected	179
Heights, corrected	108

9. *Class 3.*—Accounts, returns, correspondence, as usual.

10. *Class 4.*—Supply. Data in manuscript has been supplied to 21 officers; and about 680 despatches of maps, charts, forms, and books have been made.

11. *Class 5.*—Press copy.

N. W. Q.—Re-transcribed, revised and compared degree lists 29 to 40 of North-West Himalaya series; and prepared a general alphabetical list of names of all the stations and points fixed on this series.

S. E. Q.—Azimuthal observations completed. Some re-transcription and a good deal of re-comparison found necessary in the matter set up for the synoptical volumes. Differences of height and height above mean sea-level revised for the East Coast Series.

N. E. Q.—Orthography of principal stations examined and revised; alphabetical and numerical lists prepared for the Assam, East Calcutta, Brahmaputra and Eastern Frontier Series. Descriptions prepared for the Budhon, Rangír, Karára, East Calcutta, Brahmaputra and Eastern Frontier Series. Reduction of figures, principal triangles, and synopses of latitudes, longitudes and azimuths prepared for the entire quadrilateral; and differences of height about half-ready. Abstract of angles prepared for the Budhon, Rangír, Assam and Brahmaputra Series; and the table of "sums of squares" prepared for the Assam, East Calcutta, Brahmaputra and Eastern Frontier Series.

S. W. Q.—Alphabetical and numerical lists prepared, and descriptions of stations partly prepared for all the series of this quadrilateral; also abstract of angles prepared for the Bombay Longitudinal Series.

Southern Trigon.—Abstract of angles prepared for the South Konkan, Mangalore, and Madras Meridional and Longitudinal Series (needs comparison to a large extent).

Miscellaneous.—Central Provinces, Hyderabad and Bombay, authorized lists of spellings of proper names re-arranged alphabetically for office use. Copy of spirit levelled heights, No. 2 Southern India, examined prior to sending to press. Introduction to volume of the Great Arc Series, Section 18° to 24°, and Appendix No. 7 to Volume II of the Account of the Operations, &c., prepared.

12. *Class 6.*—*Press proofs.* These are not susceptible of explanatory remarks. An estimate of the labour involved is supplied by the fact that 17 per cent. of the entire working power of the Calculating branch was necessarily absorbed by this subject.

13. *Class 7.*—Charts.

	Name.	Compiled or revised letter press.	Examined or compared.
		Pages.	Sheets.
Preliminary.	Madras Coast and Ceylon Connection, Season 1875-76	5	1
	Jodhpur Series, Season 1875-76	3	1
	Jeysulmere and Balmer Minor Series, Season 1875-76	5	1
	Eastern Frontier Series, Season 1875-76	7	1 in part.
	Thayetmyo, Prome and Myanoung Triangulation, Season 1875-76 ...	9	1
	Pegu, Rangoon and Coast Triangulation, Season 1875-76 ...	6	1
	Assam Valley Triangulation, Season 1875-76	......	1 in part.
	Charts of Spirit Levelling Operations, Nos. 13, 19, 26, 39 ...	32	......
	Index Chart of S. W. Q. Triangulation	......	1
	Chart shewing all the principal stations in Hyderabad	......	1
	Chart to illustrate Spirit Levelled Heights, No. 2 Southern India ...	......	2
Final.	N. W. Himalaya Series, Degree Sheets Nos. 22 to 40	......	11
	Reduction Chart, S. E. Quadrilateral	......	1
	Great Arc Series, Section 18 °to 24°, No. 2	......	1
	Bilaspur Series, No. 1	......	1

14. *Class 8.—Stations.* Ten duplicate lists added, making a total of 323 settled districts accounting for 3,010 principal stations, and leaving about 20 districts yet to be settled. Four new lists accounting for 14 stations, and 42 duplicate or supplementary lists descriptive of 292 stations supplied (several in duplicate) to district officials.

TYPOGRAPHIC BRANCH.

16. The work annually performed or proportionally deduced may be briefly stated thus where the unit of a page is as heretofore taken at a certain standard size to make the total numbers comparable.

	1872-73.	1873-74.	1874-75.	1875-76.	1876-77
Pages composed ...	1,420	1,220	*1,319	*1,179	*1,535
„ printed ...	273,157	388,420	*372,647	*349,000	*495,573

The total pages composed during the eleven months under review may be sub-divided thus—

For volumes of the Great Trigonometrical Survey	1,098
„ Charts, memos., &c.	200
„ Annual Report	88
„ Pamphlet of spirit-levelled heights	21
Total ...	1,407

The large increase in the out-turn of printed pages is partly due to fortuitous circumstances.

PHOTOGRAPHIC BRANCH.

17. The following are details of the work executed by this Branch.

Maps.

Subject.	When published.	No. of parts.	No. of copies printed.
Prints of maps published in former years	...	46	1,437
Goalpara Forest Map ... For Forest Department ...	October 1876 ...	1	645
Palamau „ „ ... For Forest Department	„ „ ...	1	521
Ranikhet Map, Skeleton, *reduced*	„ „ ...	1	69
Guzerat Survey, Sheet No. 14, Section 16	„ „ ...	1	112
Dehra Dún and Siwálik Survey, Sheet No. XVI For Forest Department	November „ ...	1	142
„ „ „ „ „ „ XVII For Forest Department ...	„ „ ...	1	149
Index to Dehra Dún and Siwálik Survey	„ „ ...	1	424
„ Jaunsar Survey	„ „ ...	1	428
Spirit Levelling Operations, No. 42	„ „ ...	1	115
Ranikhet Map, Contoured, *reduced*	„ „ ...	1	87
Index to Guzerat Survey	December „ ...	1	436
„ to Triangulation by the Great Trigonometrical Survey of India. For Officiating Superintendent's Administration Report, 1875-76	„ „ ...	1	444
„ to main lines of levels (reduced scale)	„ „ ...	1	423
Route Map. For Captain Biddulph	„ „ ...	1	139
Byragarh Forest Map. For Forest Department	„ „ ...	1	100
Kumaun and Garhwál, Sheet No. 20, Skeleton ...	„ „ ...	1	158
Dehra Dún and Siwálik Survey, Sheet No. XVIII ... For Forest Department	January 1877 ...	1	146
„ „ „ „ „ XXVI ... For Forest Department	„ „ ...	1	140
„ „ „ „ „ XXVII . For Forest Department	„ „ ...	1	145

* Averages for a twelve-month.

Maps—continued.

Subject.	When published.	No. of parts.	No. of copies printed.
Spirit Leveling Operations, No. 19	January 1877 ...	1	110
„ „ „ „ 25	„ „ ...	1	109
„ „ „ „ 41	„ „ ..	1	107
Index to Kattywar Survey	„ „ ...	1	400
Hyderabad Territory, Skeleton Map, showing Sub-divisions and Great Trigonometrical Survey Principal Stations	„ „ ...	1	95
Index to Triangulation, S. W. Quadrilateral	February „ ...	1	29
Dehra Dún and Siwálik Survey, Sheet No. XLI. For Forest Department	„ „ ...	1	133
Kumaun and Garhwál, Sheet No. 21, Contoured	„ „ ...	1	108
Guzerat Survey, Sheet No. 81, Section 7	March „ ...	1	106
„ „ „ „ 14, „ 13	„ „ ..	1	119
„ „ „ „ 14, „ 15	„ „ ...	1	107
Kattywar Survey, Sheet No. 36	„ „ ...	1	135
Dehra Dún and Siwálik Survey, Sheet No. XXXV. For Forest Department	April „ ...	1	14C
Guzerat Survey, Sheet No. 81, Section 16	„ „ ...	1	107
Kattywar Survey, Sheet No. 45	„ „ ...	1	134
Dehra Dún and Siwálik Survey, Sheet No. XXV	„ „ .	1	142
Kumaun and Garhwál, Sheet No. 19, Skeleton	„ „ ...	1	165
Mussoorie and Landour Survey, Sheet No. 13, Skeleton, 2nd Edition	„ „ ...	1	35
„ „ „ „ „ Contoured „	„ „ ...	1	37
Kattywar Survey, Sheet No. 10*a*	May „ ...	1	136
Kumaun and Garhwal, Sheet No. 11, Skeleton	„ „ ...	1	165
„ „ „ „ 24, „	„ „ ...	1	166
„ „ „ „ 30, „	„ „ ...	1	163
„ „ „ „ 7, „	„ „ ...	1	170
Guzerat Survey, Sheet No. 81, Section 8	„ „ ...	1	88
Kattywar Survey, Sheet No. 37	June „ ...	1	133
Guzerat Survey, Sheet No. 82, Section 2	„ „ ...	1	86
„ „ „ „ 82, „ 5	„ „ ...	1	87
„ „ „ „ 81, „ 16	„ „ ...	1	87
„ „ „ „ 81, „ 14	„ „ ...	1	85
Spirit Leveling Operations, No. 39	„ „ ...	1	119
Guzerat Survey, Sheet No. 81, Section 13	July „ ...	1	87
„ „ „ „ 82, „ 4	„ „ ...	1	90
„ „ „ „ 14, „ 14	„ „ ...	1	85
Spirit Leveling Operations, No. 26	„ „ ...	1	111
Guzerat Survey, Sheet No. 80, Section 16	August „ ...	1	89
„ „ „ „ 82, „ 1	„ „ ...	1	87
„ „ „ „ 82, „ 3	„ „ ...	1	86
„ „ „ „ 14, „ 2	„ „ ...	1	87
Kattywar Survey, Sheet No. 38	„ „ ...	1	135
Route Map, illustrating the Mullah's explorations in 1876 ...	„ „ ...	1	505
Dehra Dún and Siwálik Survey, Sheet No. XXX	„ „ ...	1	134
Spirit Leveling Operations, No. 13	September „ ...	1	110
Mussoorie and Landour, Sheet No. 19, Skeleton, 2nd Edition ...	„ „ ...	1	35
„ „ „ „ 19, Contoured „ ...	„ „ ...	1	35
„ „ „ „ 14, „ „ ...	„ „ ...	1	40
„ „ „ „ 15, „ „ ...	„ „ ...	1	37
Dehra Dún and Siwálik Survey, Sheet No. XXII	„ „ ...	1	143
Guzerat Survey, Sheet No. 14, Section 4	„ „ ...	1	87
„ „ „ „ 14, „ 6	„ „ ...	1	92
„ „ „ „ 14, „ 7	„ „ ...	1	88
Kattywar Survey, Sheet No. 50	„ „ ...	1	123
	Totals ...	117	12,348

Besides the foregoing, 108 blue-prints were issued, and 189 sets of silver prints (59 subjects) were prepared for the use of the engravers and for Executive Officers.

Charts.

Subject.	When published.	No. of parts.	No. of copies printed.
North-West Himalaya Series, Degree Sheet No. 7, final ...	October 1876 ..	1	390
„ „ „ „ „ „ 14—15, „ ...	„ „ ...	1	375
„ „ „ „ „ „ 5—6, „ ...	November „ ...	1	435
„ „ „ „ „ „ 12, „ ...	„ „ ...	1	352
„ „ „ „ „ „ 13, „ ...	December „ ...	1	355
„ „ „ „ „ „ 10—11, „ ...	„ „ ...	1	371
„ „ „ „ „ „ 8—9, „ ...	January 1877 ...	1	377
„ „ „ „ „ „ 18, „ ...	„ „ ...	1	425
„ „ „ „ „ „ 16—17, „ ...	„ „ ...	1	431
„ „ „ „ „ „ 19, „ ...	February „ ...	1	375
„ „ „ „ „ „ 20, „ ...	„ „ ...	1	367
„ „ „ „ „ „ 21, „ ...	„ „ ...	1	374
Jodhpur Series, Season 1875-76, Numerical	„ „ ...	1	67

Charts—continued.

Subject.	When published.	No. of parts.	No. of copies printed.
North-West Himalaya Series, Degree Sheet No. 22—23, Final ...	March 1877 ...	1	366
" " " " " " 24, " ...	" " ...	1	375
" " " " " " 25, " ...	" " ...	1	373
" " " " " " 26—27, " ...	" " ...	1	426
Madras Coast and Ceylon Connection Series, Season 1875-76, Numerical	" " ...	1	66
Jeysulmere and Balmer Series (Secondary), Season 1875-76, Numerical	" " ...	1	67
North-West Himalaya Series, Degree Sheet No. 37, Final ...	April " ..	1	402
" " " " " " 31—35, " ...	May " ...	1	377
" " " " " " 36—38, " ...	" " ...	1	315
" " " " " " 30—34, " ...	" " ...	1	367
" " " " " " 39—40, " ...	June " ...	1	356
" " " " " " 32—33, " ...	" " ...	1	382
" " " " " " 28—29, " ...	" " ...	1	380
Eastern Frontier Series, Season 1875-76, Numerical...	" " ...	1	65
Thayetmyo and Prome Triangulation (Secondary), Season 1875-76, Numerical	" " ...	1	80
Pegu, Rangoon, and Coast Triangulation (Secondary), Season 1875-76, Numerical	August " ...	1	70
Assam Valley Triangulation, 1875-76, Numerical	" " ...	1	65
	Totals ...	30	9,225

Diagrams.

Subject.	When published.	No. of copies printed.
Polygons and other figures to illustrate figural reductions for Vols. of the Great Trigonometrical Survey, Bench Marks, &c.	October 1876 ...	483
	November " ...	466
	December " ...	300
	January 1877 ...	433
	February " ...	255
	July " ...	1,928
	August " ...	91
	Total ...	3,956
Professional and Office Forms	1876-77 ...	21,384

Contrasting the work performed since 1872-73, we have—

Year.	Maps.	Blue-prints.	Silver prints.	Charts.	Diagrams.	Forms.
1872-73	6,910	Not reckoned.	Not reckoned.	2,206	12,055	12,549
1873-74	9,207	53	...	2,027	3,557	28,125
1874-75	7,040*	20*	...	3,015*	3,701*	24,219*
1875-76	14,025	12	126	1,678	9,722	18,314
1876-77	12,348	108	189	9,225	3,956	21,384

An abstract of the work executed during the past five years stands thus,—

Subject.	Number of Prints.				
	1872-73.	1873-74.	1874-75.	1875-76.	1876-77.
Maps, Charts, and Diagrams	21,171	14,791	13,756*	25,425	25,529
Blue-prints and Silver-prints	Not reckoned.	Not reckoned.	20*	138	297
Forms	12,549	28,125	24,219*	18,314	21,384

The increase in the number of prints of Charts in 1876-77 is due chiefly to the copies required for illustrating our synoptical volumes; the increase of maps in 1875-76-77 arises from a corresponding increase in the number of originals presented for photozincography.

* Averages for a twelve month.

Drawing Branch.

(18). The principal work performed in this branch during the 12 months ended 30th September 1877 is detailed in the following table:—

DESCRIPTION OF WORK.	NUMBER OF SHEETS OR DIAGRAMS. Finished.	In hand.	Scale 1 inch =	REMARKS.
COMPILATION.			Miles.	
Map to illustrate explorations made in connection with the operations of the Great Trigonometrical Survey of India in 1876 by "The Mullah," with hill shading.	1	...	8	For Photozinc: Reduction to ⅔ scale.
Map to illustrate Captain Biddulph's route from Bunji *viâ* Gilgit towards the Karambar Pass and to Hunza, with hill shading.	1	...	8	Ditto.
Chart to illustrate the Electro-Telegraphic determinations of differences of Longitude.	1	...	96	Ditto.
Index to main lines of levels by the Great Trigonometrical Survey, 2nd Edition, with corrections and additions to 1876.	1	...	40	Ditto. Reduction to ⅓ scale.
Map of Trans-North-Western Frontier Region ...	...	1	4	Ditto.
Rough Chart of the South-West Quadrilateral Triangulation.	1	...	24	Ditto.
Chart illustrating the "Reduction of the South-West Quadrilateral."	1	...	12	Ditto. Reduction to ½ scale.
Sketch Map of the Hyderabad Territory, shewing sub-divisions and positions of principal stations of the Great Trigonometrical Survey.	1	...	16	Ditto.
Chart No. 1, illustrating Spirit Leveling Operations of the Great Trigonometrical Survey in 1873-74.	1	...	10	Ditto Reduction to ⅓ scale.
Chart No 2, illustrating Spirit Leveling Operations of the Great Trigonometrical Survey in 1874-75.	1	...	12	Ditto ditto ⅔ scale.
Sheet No. 13 of Spirit Leveled Heights ...	1	...	2	Ditto.
Do. " 19 do. do.	1	...	2	Ditto.
Do. " 26 do. do.	1	...	2	Ditto.
Do. " 39 do. do.	1	...	2	Ditto.
Do. " 53 do. do.	...	1	2	Ditto.
Do. " 59 do. do	...	1	2	Ditto.
Do. " 2 Dehra Dún and Siwâliks ...	...	1	1	Ditto.
Do. " 24 do. do. survey ...	1	...	¼	Ditto.
Do " 32 do. do. do. ...	1	...	¼	Ditto.
Do. " 40 do. do. do. ...	1	...	¼	Ditto.
FINAL CHARTS.				
Great Arc Series, Section 18° to 24° (Secondary Triangulation.)	2	...	4	Ditto Reduction to ⅓ scale.
Bilâspur Meridional Series	2	...	4	Ditto ditto.
Calcutta Longitudinal Series	.	3	4	Ditto ditto.
Jubbulpore Meridional Series	...	2	4	Ditto ditto.
Bider Longitudinal Series	...	2	4	Ditto ditto.
PRELIMINARY NUMERICAL CHARTS.				
Jeysulmere and Balmer Minor Series, Season 1875-76	1	...	4	Ditto.
Secondary Triangulation—Pegu, Rangoon, and Coast, Season 1875-76.	1	...	4	Ditto.
Secondary Triangulation—Thayetmyo *viâ* Prome and Myanaung towards Bassein and Cape Negrais, Season 1875-76.	1	...	4	Ditto.
MISCELLANEOUS.				
Examined and reported on 65 fair original maps of Kumaun and Garhwál, Kattywar, Guzerat, and Dehra Dhún and Siwâliks Surveys				
Examined 118 proofs of Maps and Charts ...				
Colored 6,313 Maps				

Taking Stock.

(19). In addition to the foregoing duties, stock was taken in all the four branches, as usual shortly after 1st January, of all records, books and stores belonging to the office.

Meteorological results

(20). Tables of monthly meteorological results are herewith appended as usual.

Monthly meteorological results taken from the Register kept at the Office of the Superintendent, Great Trigonometrical Survey of India, Dehra Dún.

Year and Month.	Barometer. H. M. At 9·30 A. M. Highest.	Barometer. H. M. At 9·30 A. M. Lowest.	Barometer. H. M. At 9·30 A. M. Monthly mean.	Barometer. H. M. At 3·30 P. M. Highest.	Barometer. H. M. At 3·30 P. M. Lowest.	Barometer. H. M. At 3·30 P. M. Monthly mean.	Hygrometer. H. M. At 9·30 A. M. Monthly mean Temperature of Dew point.	Hygrometer. H. M. At 9·30 A. M. Monthly mean Humidity.	Hygrometer. H. M. At 3·30 P. M. Monthly mean Temperature of Dew point.	Hygrometer. H. M. At 3·30 P. M. Monthly mean Humidity.	Thermometer. Dry Bulb. Maximum in Sun's rays.	Thermometer. Dry Bulb. Minimum on grass.	Thermometer. Dry Bulb. Maximum in air.	Thermometer. Dry Bulb. Minimum in air.	Thermometer. Dry Bulb. Monthly mean in air.	Thermometer. Wet Bulb. Maximum wet.	Thermometer. Wet Bulb. Minimum wet.	Thermometer. Wet Bulb. Monthly mean wet.	Rain. No. of days it fell.	Rain. Fall in inches.	Wind. Most frequent direction.	Cloud. H. M. At 9·30 A. M.	Cloud. H. M. At 3·30 P. M.
1876.																							
November ...	27·874	27·650	27·766	27·797	27·555	27·687	51·7	·662	52·5	·505	88·6	39·0	79·2	43·0	62·8	66·0	32·0	51·1	...	...	N. & W.	1	2
December ...	·951	·729	·844	·838	·641	·758	45·8	·675	47·4	·490	81·7	37·0	71·2	41·4	56·8	61·1	28·8	45·9	...	..	N.W.&S.	1	2
1877.																							
January ...	·973	·708	·861	·901	·629	·775	47·1	·790	47·2	·564	81·5	34·4	71·8	31.9	55·6	59·3	36·4	48·5	8	3·09	W. & S.	4	5
February ...	·890	·497	·775	·824	·431	·704	45·9	·785	45·8	·539	88·6	30·0	76·5	35·2	54·1	62·1	33·8	46·9	8	4·41	W. & S.	3	4
March ...	·820	·604	·709	·736	·525	·630	52·6	·668	52·4	·485	92·5	42·0	82·3	45·8	64·5	67·5	41·7	54·7	10	2·64	W.N.&E.	5	6
April ...	·784	·507	·673	·751	·452	·590	56·4	·576	54·4	·426	102·9	44·8	90·1	50·0	70·2	71·0	43·4	57·6	6	1·92	N.W.&E.	3	5
May ...	·671	·368	·554	·578	·326	·468	62·5	·524	60·7	426	113·6	55·8	104·0	59·0	79·1	75·2	44·3	62·3	8	2 73	E. & N.	2	3
June ...	·610	·257	·447	·542	·202	·364	70·5	·593	69·0	·478	115·0	63·6	102·0	67·1	84·3	81·2	55·0	69·5	8	4·40	N.E.&W.	2	3
July ...	·540	·308	·386	·459	·249	·328	74·3	·730	75·6	·641	111·5	66·0	95·7	68·3	83·0	82·0	62·1	73·9	11	6·94	N. & W.	5	5
August ...	·649	·256	·441	·525	·213	·367	73·3	·717	74·7	·635	112·4	66·7	95·1	68·2	82·5	82·0	62·8	73·5	9	9·07	S. & W.	4	4
September ...	·677	·409	·572	·573	·329	·480	68·4	·633	69·3	·537	109·3	60·7	92·0	64·0	80·5	80·2	53·7	69·7	3	1·39	N.N.&E.	2	3
October ...	·868	·634	·747	·770	·528	·655	58·6	·605	57·5	·486	104·8	50·4	91·1	55·1	72·7	74·3	44·9	59·1	5	·69	N.N.&E.	2	3

Note.—The height of the Barometer Cistern above mean sea-level at Karáchi is 2,232·41 feet.

Mean Velocity in miles of the winds which blew at Dehra during 12 months of 1876-77 for each hour of the day.

Civil Hours.	October.	November.	December.	January.	February.	March.	April	May.	June.	July.	August.	September.
0 to 1	2·70	3·27	2·89	2·20	1·78	2·68	2·33	2·50	2·50	2·65	2·03	2·73
1 „ 2	2 30	2·47	2·63	2·32	1·11	1·96	1·50	2·03	2·17	1·73	1·84	2·63
2 „ 3	2·19	2·77	2·56	2·04	0·96	1·75	2·20	1·87	1·50	1·58	1·13	2 47
3 „ 4	2·19	1·90	1·96	1·84	1·26	1·43	1·30	1·52	1·43	1·04	1·19	2·30
4 „ 5	1·70	1·97	1·85	1·68	0·89	1·07	1·13	1·07	1·47	1·15	1·26	1·77
5 „ 6	1·59	2·00	1·78	1·92	0·89	1·32	1·33	1·28	1·40	0·69	1 68	1·80
6 „ 7	1·70	1·80	2 07	1·88	0·67	1·29	0·97	0·76	1·57	1·12	1·19	1·57
7 „ 8	0 78	1·50	1·30	1·56	0·74	1·32	1·30	0·86	1·20	1·35	0·94	1·33
8 „ 9	1·56	1·40	0·93	1·72	0 85	1·50	1·43	1·69	1·90	2·04	1·42	1·37
9 „ 10	2·26	1·63	1·56	1·60	1·48	1·75	2·23	2·28	2·47	2·46	2·10	1·77
10 „ 11	2·96	2 37	1·61	2·12	1·96	2·32	2·80	2·62	2.83	2·38	2·00	2·10
11 „ 12	2·41	2·07	2·11	2·12	2·11	1·93	2·90	2·72	2·77	2·62	1·81	2·57
12 „ 13	2·81	3 10	2·37	2·58	2·29	2·21	4·10	3·13	3·76	2·27	1·90	2·43
13 „ 14	2·89	3·07	2·67	2·15	2·63	2·36	3·73	3·27	3·62	2·35	1 90	2·73
14 „ 15	2 78	3·07	2·33	2·08	2·48	3·07	4·47	3·60	4·10	2·42	2·29	2·57
15 „ 16	2·30	2·40	1·96	1·96	2·41	2·64	3·50	3·90	3·20	1·77	1·55	2·57
16 „ 17	1 37	0·77	1·00	1·24	2·37	3·14	3·33	3·37	2·97	1·46	1·26	1·41
17 „ 18	0·33	1·10	0·26	0·64	1·59	2·43	1·60	3·20	2·37	1·19	0·94	0·93
18 „ 19	1·48	2·43	0·89	0·72	0·89	1·36	0·73	2·20	1·30	0·54	0·77	2·00
19 „ 20	2·67	3·40	2·37	1·20	0·41	1·25	1·70	2·70	1·00	1·08	1·58	2·83
20 „ 21	2·89	3·60	2·96	2·16	1·04	1·57	1·47	2·67	1·43	1·31	2·19	3·23
21 „ 22	2·85	3·57	3·00	1·88	1·15	1·50	2·43	2·87	2·10	1·19	2·16	3·13
22 „ 23	2·93	3·30	2·96	2·32	1·19	1·64	2·33	3·30	2·17	1·69	2·29	3·63
23 „ 24	2·81	3·30	2·89	1·76	1·93	1·81	2·47	2·87	2·67	2·04	2·06	3·37
Sums ...	52·45	58·26	48·91	43·69	35·08	45·30	53·28	58·28	53·90	40·12	39·42	55·24
Average ...	2·19	2·43	2·04	1·82	1·46	1·89	2·22	2·43	2·25	1·67	1·64	2·30

Extract from the Narrative Report, dated 29th November 1877, of Major J. Herschell, R. E., on the prosecution of the reduction of Pendulum observations to Sea-level.

THE prosecution of the reduction of Captain Basevi's and Captain Heaviside's pendulum observations for varying attraction in different latitudes and at different heights has been alluded to in articles 88, 89 of the report for 1874-75 as occupying my attention. The enquiry was laid aside to enable me to attend to the business of the computing office during the following year, and I was unable to resume it until the beginning of 1877, when I was relieved of that charge.

It is not very easy to resume the thread of a subject of such intricacy. The interruption has not, however, been altogether without advantage. I have found it best to re-write the whole of what I had prepared in the first instance, in order to lead up more systematically from the comparative security of the earlier stages to the extreme uncertainty which characterizes, and, so far as I can foresee, must always characterize, the latter.

The investigations have been brought to a close, but the result can hardly be said to be satisfactory, the upshot being, in very few words, that the force of gravity (including in that term the attraction of the whole matter of the earth, wheresoever situated), as evidenced by the pendulum, remains not wholly explicable by any *known* conditions of the earth's form or constitution. Neither do the observed anomalies point with any certainty to an inference having a high degree of likelihood.

It is true that any one anomalous result may be readily explained by supposing a particular increase or decrease of density, of a particular volume of matter, in a particular direction, at a particular distance, and depth. *A fortiori*, several such influences being supposed will supply all needful disturbing actions. The range of hypothesis thus extended is scarcely limited by the condition that many anomalous results have to be simultaneously so explained. Practically, indeed, it may be said to be not limited at all; for not only are the data whose unexplained deviations are sensibly larger than may be attributed to errors of observation, few in number, but nearly all of those are *most easily* explained by approximate and independent disturbing force. There is not, in my opinion, any indication of a *common* explanation sufficiently plausible to warrant extensive investigation for the purpose of a more precise evaluation of the data, *e.g.*, for determining the effect of the known distribution of land and sea.

It would be a mistake to read this as an evasion of a great difficulty. The difficulty *is* great, but it has been faced. The theory of the subject has been sufficiently mastered to enable estimates of the possible effects to be made for the remote and precise calculations for the proximate distribution. These failed, as has been said, to explain the observations. There remained the still more difficult question of the effect to be assigned on the supposition that the sea-level, as we know it and refer to it, is very different from the level which the sea would have if it were not drawn away from its primitive rest by the masses of the existing continents. Were the attraction of these surface masses to cease, *or were it negatived by corresponding lightness in subjacent strata*, the sea would retire and its level would fall, perhaps two or three thousand feet.* Were the continents, thus apparently raised by the same amount, "cast into the sea," in such a manner as to equalize its depth over the whole earth, the level would be again altered. All these changes, invented to reinstate the earth, so to speak, in a condition of more perfect regularity of figure, would involve alterations of attractive effect: *vice versâ* the change from the hypothetical primitive condition to that which now exists has involved disturbances of the previous state of attraction, which, it is presumable, are present in the force of gravity as we find it.

This part of the subject can only be treated by mathematics of a higher order than inadequate familiarity enables us to safely employ. Partly on this account, and partly from the very obvious consideration that widespreading causes of this character have too gradually varying effects to account for the abrupt anomalies of a local group, it has not been thought advisable to pass from investigation to calculation. Lines have, however, been traced, which it is hoped may be of service should the enquiry have hereafter to advance.

There are three stations of the Indian group which are of exceptional importance, *viz.*, Dehra, Mussoorie, and Moré. The first two form a pair, about 10 miles apart and differing 4,600 feet in elevation, upon the skirts of the Himalayas; the third is in the middle of the Himalayan range, at an elevation of 15,400. But for these three, the Indian group would have taken its place among other pendulum stations, and would have lent itself sufficiently to the various explanations which have been framed to account for the anomalies which appear so generally in this class of work. These, on the contrary, defy those explanations. Accepting the vibration-number as practically the true measure of gravity at a spot, there is no way of accounting for the discrepancy of $3\frac{1}{2}$ vibrations per diem between the above named pair, after all known corrections have been applied, except by supposing a quite local variation of density, such as would suffice to cover the discrepancies at most of the other stations. If we must accept this as a fact, what need to reduce with extreme precision?

The case is quite analogous to what was long ago shown regarding latitudes, and only needs verification as regards azimuths.

The case of Moré differs in this, that there is no nearer comparison than with the numbers at the former pair. There would seem to be some 20 vibrations here unsusceptible of present explanation, if we accept that offered by the contested hypothesis of Sub-Himalayan tenuity.

I am not prepared to accept or reject that hypothesis, still less to discuss it here. It must be approached, if at all, from the geological side; and as the earth is held by some to be solid internally, and by others fluid, there are probably arguments against it as well as for it. It is, however, remarkable that the column of results obtained by separating the height-correction (by Young's rule) into its two proper components, and adopting the first only, *viz.*, that for mere elevation, is *more accordant* throughout than that which follows it, where the correction for subjacent mass is also applied. The hypothesis of Sub-Himalayan tenuity would forbid this last application, and derives, therefore, some support from the fact.

Nevertheless, I am constrained to say that it is impossible at present to adopt that or any other hypothesis, except as an inference; and that the broad conclusion to which I am led is this—pendulum results are subject to errors which we have no prospect of eliminating, and therefore their *accuracy of observation* should be regulated with regard to the *magnitude* of those errors, and their *frequency of locality* increased, both locally and widely:—locally, in order to extend our knowledge of the measure of this natural error or uncertainty; widely, in view of the fact that, at present, measures of gravity are the only kind of measure of a geodetic character which can be extended with any approach to generality over the whole globe.

* The form of this sentence expresses intentionally the opinion which, in common with many geodesists, I feel bound to retain as the *safe* one, until the alternative italicised in the text has a good claim to supersede it. What follows necessarily ignores that alternative; but does not deny it.

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INDEX TO LEVEL CHARTS OF