November 24, 1870.

General Sir EDWARD SABINE, K.C.B., President, in the Chair.

In pursuance of the Statutes, notice was given from the Chair of the ensuing Anniversary Meeting, and the list of Officers and Council proposed for election was read as follows:—

President.—General Sir Edward Sabine, R.A., K.C.B., D.C.L., LL.D.

Treasurer.—William Spottiswoode, Esq., M.A.

Secretaries.— { William Sharpey, M.D., LL.D.
George Gabriel Stokes, Esq., M.A., D.C.L., LL.D.

Foreign Secretary.—Prof. William Hallowes Miller, M.A., LL.D.

Other Members of the Council.—George Burrows, M.D.; Heinrich Debus, Esq., Ph.D.; Prof. Peter Martin Duncan, M.B.; Sir Philip de M. Grey-Egerton, Bart.; Prof. George Carey Foster, B.A.; Francis Galton, Esq.; John Peter Gassiot, Esq., D.C.L.; Joseph Dalton Hooker, C.B., M.D.; William Huggins, Esq., D.C.L., LL.D.; Prof. George M. Humphry, M.D.; John Gwyn Jeffreys, Esq.; Sir John Lubbock, Bart.; Charles William Siemens, Esq., D.C.L.; Prof. Henry J. Stephen Smith, M.A.; Prof. John Tyndall, LL.D.; Prof. Alexander W. Williamson, Ph.D.

Pursuant to notice given at the last Meeting, Sir John Rennie proposed and General Boileau seconded His Grace the Duke of Sutherland for election and immediate ballot.

The ballot having been taken, the Duke of Sutherland was declared duly elected.

Pursuant to notice given at the last Meeting, Anders Jöns Ångström, of Upsala, and Joseph Antoine Ferdinand Plateau, of Ghent, were ballotted for and elected Foreign Members of the Society.

The following communications were read:—

I. "Communication from the Secretary of State for India relative to Pendulum Observations now in progress in India in connexion with the Great Trigonometrical Survey under the Superintendence of Colonel J. T. Walker, R.E., F.R.S." Read by order of the President and Council.

India Office, S.W., 3rd October, 1870.

Sir,—I am directed by the Secretary of State for India to transmit to you, for the information of the President and Council of the Royal Society, the enclosed copy of a letter from Colonel Walker, the Superintendent of the Great Trigonometrical Survey of India, on the pendulum-observations that have been carried on since 1865 by Captain Basevi, together with a note, tabulated results, and a Map of India showing the pendulum-stations.

The Duke of Argyll will be obliged if, in accordance with Colonel Walker's wish, the President and Council would be so good as to furnish

His Grace with any suggestions that may occur to them with reference to supplementary measures that may appear necessary in order to complete the operations which were commenced at the suggestion of General Sabine, and with the concurrence of the Council.

I am, Sir,

Your obedient Servant,

J. Cosmo Melvill.

The Secretary to the Royal Society.

Enclosure No. 1.

Government of India, Home Department—Geographical.

To His Grace the Right Honourable the Duke of Argyll, Kt., Her Majesty's Secretary of State for India.

Simla, the 26th of August, 1870.

My Lord Duke,—Referring to Sir Charles Wood's despatch in the Military Department No. 271, dated the 23rd of August, 1864, authorizing the carrying out of certain pendulum experiments in connexion with the operations of the Great Trigonometrical Survey of India, at the recommendation of the President and Council of the Royal Society, we have the honour to transmit, for your Grace's information, copy of a letter from Colonel Walker, No. 49–793, dated the 11th instant, together with its enclosures, showing what has been done and what remains to be done to complete the original programme.

2. With reference to the last paragraph of Colonel Walker's letter, we beg that the President and Council of the Royal Society may be invited to suggest, at an early date, any supplementary measures which they may consider desirable.

We have the honour to be,

My Lord Duke,

Your Grace's most obedient, humble Servants,

Mayo.
Napier of Magdala.
John Strachey.
R. Temple.
J. F. Stephen.
B. H. Ellis.
H. W. Norman.

Enclosure No. 2.

From Colonel J. T. Walker, R.E., Superintendent Great Trigonometrical Survey of India, to the Secretary to the Government of India, Home Department, Simla.

Dated Mussoorie, 11th August, 1870.

Sir,—I have the honour to report that the pendulum-observations which have been carried on since the year 1865, by Captain Basevi, in con-

nexion with the operations of the Trigonometrical Survey of India, at the recommendation of the President and Council of the Royal Society, are now nearly completed, in conformity with the original programme of operations which was sanctioned by the Right Honourable the Secretary of State for India, in his military letter No. 271, dated 23rd August 1864, to the Governor-General in Council.

(2.) The results are of much importance, not only as affording independent information on the figure of the earth, but as throwing some light on "the laws of the local variations of gravity which are superposed on the grand variation from the poles to the equator;" thus it will, I trust, be conceded that they amply fulfil the purposes contemplated in the 'Correspondence and Proceedings of the Council of the Royal Society concerning Pendulum-Observations in India.'

(3.) But, before the operations are brought to a close, I think it is desirable that the President and Council of the Royal Society should be informed of what has been done hitherto, and of what remains to be done to carry out the original programme of operations; also that they should be invited to suggest any supplementary measures which they may consider necessary in order to complete the operations, and thus perfect a work which was commenced at the suggestion of the President and with the hearty approval of the Council, and in the success of which they take a lively interest.

(4.) I have therefore prepared the accompanying note on the operations in explanation of what has been done hitherto, and of what remains to be done to complete the original programme; and I beg leave to request that the Secretary of State may be moved to communicate it to the President and Council of the Royal Society, and to invite their opinions and suggestions. The Note is accompanied with a map on which the positions of the pendulum stations are indicated.

I have the honour to be, Sir,
Your most obedient Servant,
J. T. Walker, Colonel R.E.,
Supdt. Great Trigonometrical Survey of India.

Note on the Pendulum-observations in India, which are being carried on by Captain J. P. Basevi, in connexion with the operations of the Great Trigonometrical Survey of India.

The observations have been made with the two invariable pendulums of the Royal Society, which are known as No. 4 and No. 1821. The number of vibrations in twenty-four hours is determined by observing the coincidences of each pendulum with the pendulum of a clock by Shelton, which is also the property of the Royal Society. The pendulums are swung, one at a time, in the receiver of a vacuum apparatus out of which as much air as possible is withdrawn by an air-pump, and the rate of the clock is determined every night.

(2.) Captain Basevi's daily course of procedure is as follows. At 6 A.M. he sets in motion the pendulum which is under observation. At 7 A.M. he observes three coincidences and reads the thermometers and pressure-gauge. Between 7 A.M. and 4 P.M. he observes a coincidence and reads the thermometers and the gauge, five times at intervals of $1\frac{1}{2}$ hour. At 4 P.M. he closes this portion of the work by observing three coincidences and again reading the thermometers and the gauge. Thus for nearly ten hours of the day Captain Basevi never permits himself to be absent for more than a few minutes at a time from the pendulums. These frequent observations are necessary in order that the temperatures may be exactly determined. At 8 to 10 P.M. he observes transits.

(3.) Originally it was expected that, by employing a vacuum-apparatus, the pendulum might be vibrated for twenty-four hours before the vibrations became too small for the observation of coincidences, and consequently that the rate derived from the coincidences would be wholly independent of irregularities in the clock's rate in different parts of the twenty-four hours. But this would have necessitated observations of the temperature at regular intervals throughout the twenty-four hours, which, as a rule, would have been impossible, though a few such groups of observations have been taken experimentally. Moreover at the commencement of the operations the vacuum-cylinder could not be made sufficiently air-tight to admit of so protracted an observation.

(4.) Each pendulum is observed a certain number of days with the face to the front, and then as many days with the face to the rear. At the first four stations observations were taken for five days on each face, making altogether twenty days' observations for both pendulums; as, however, it was found that the theoretical probable error of the mean of the ten days' observations by a single pendulum was only $\pm$·05 of a vibration, the number of observations was subsequently limited to six days on both faces, making altogether twelve days' work at each station.

(5.) The observations are now being printed in the office of the Trigonometrical Survey, and a few specimen pages accompany this note. A preliminary abstract of the mean results by both pendulums is also given, and a map indicating the positions of the stations of observation*.

(6.) The results obtained hitherto are not final; the coefficients of the corrections for temperature and pressure have not yet been conclusively determined, and the reductions to mean sea-level will probably be effected when the calculations of the influence of local irregularities in the crust of the earth have been carried to a greater distance from the stations than has hitherto been practicable.

(7.) Of these corrections the most important is that for temperature; the mean temperature of the observations ascends from a minimum of 54° at the base station Kew, to a maximum of 88° at Namthabad, being a

* [It has not been thought requisite to publish this map.—G. G. S.]

range of 34°; as the correction is approximately equal to one vibration for 2° of temperature, or seventeen vibrations for the extreme range, the true value must necessarily be determined with the utmost possible accuracy.

(8.) In Section XIII. of my General Report on the Operations of the Trigonometrical Survey for 1866–67, I have fully described certain measures which were taken to determine the coefficient of linear expansion. Briefly, they were as follows: vibrations were observed, at high and low temperatures, under the lowest pressure which could be obtained in the vacuum-apparatus at Kaliana, and at the natural pressure at Masoori; the expansions were also determined at high and low temperatures by direct micrometric measurement, with the following results :—

	Pressure, in inches.	Factor of expansion for 1° Fahrenheit.	
At Kaliana ..	3·5	000,011,10	by vibrations.
„ Masoori ..	23·5	000,010,01	by vibrations.
„ Dehra	27·7	000,009,73	by direct measurement.

Thus the value of the expansion which was determined from vibrations under a pressure of 3·5 inches was 14 per cent. greater than the value determined by direct measurement, at the natural pressure. I stated in my report that "whether this is due to an actual increase of expansion for a decrease of pressure or to the action of other phenomena which are at present unknown or only imperfectly known, is a problem for future solution."

(9.) Experiments have been made at the Kew Observatory for the purpose of investigating this question; they are described in the 'Proceedings of the Royal Society,' No. 113, 1869. Owing, however, to difficulties which were experienced in working with artificial temperatures, the results were not conclusive as regards the present difficulty, and the hope was expressed that the question would find its best solution by our labours in India.

(10.) The temperature-coefficients which have been employed in the preliminary reductions are those which were obtained from the observations at Kaliana, viz.:

For No. 4 pendulum 0·485 vibration per diem for 1° Fahrenheit.
„ No. 1821 „ 0·470 „ „ „

(11.) The pressure-coefficient which has been employed hitherto is the mean of the two values determined at Kew, or 0·32 vibration per diem for each inch of pressure at 32° Fahrenheit.

(12.) In the reductions to the sea-level, the surface-density has been assumed to be half the mean density of the earth. Dr. Young's formula has been used exclusively for stations situated on tolerably level plains, but for stations on hills the observations have been first reduced to the general level of the country by computing the vertical attraction of the elevated mass down to this level, the mass being divided into a number of

compartments by concentric circles and radii; they have then been reduced to the sea-level by Dr. Young's formula. The stations thus corrected are Masoori, Usira, Ehmadpur, and Somtana; at Masoori, curvature was taken into account, and the calculations were extended to a distance of 100 miles all round; but at the three other stations curvature was not allowed for, as the calculations were only carried to a distance of one mile.

(13.) The preceding details will suffice to explain all that is necessary regarding the observations, and the preliminary results which have been derived therefrom which accompany this note. I will therefore now proceed to indicate the principles by which we have been guided in selecting the positions of the pendulum-stations.

(14.) In the first instance, the original programme of observing at a certain number of stations of the Great Arc was duly carried out; the pendulums were swung at eighteen stations between Cape Comorin and the Siwalik Hills at the base of the southern slopes of the Himalayas, and at two stations north of the Siwaliks.

(15.) As yet no observations have been taken on the higher ranges, or on the tablelands, of the Himalayas, and thus the full influence of these ranges in producing local variations of gravity has not yet been ascertained. But the observations at the five northernmost stations indicate that there is much probability that the density of the strata of the earth's crust under and in the vicinity of the Himalayan mountains is less than that under the plains to the south, the deficiency increasing as the stations approach the Himalayas, and being greatest when they are north of the Siwaliks. On the other hand, the observations at the five southernmost stations show an increase of density in proceeding from the interior of the Peninsula to the coast of Cape Comorin. Thus both groups of observations tend to confirm the hypothesis that there is a diminution of density in the strata of the earth's crust under mountains and continents, and an increase of density under the bed of the ocean.

(16.) In order to test this hypothesis still further, as soon as the observations at the stations of the Meridional Arc were completed, the pendulums were taken to an ocean station—the Island of Minicoy, in the same latitude as Punnæ, and about 250 miles from the mainland; and afterwards to five stations on the east and west coasts, each in nearly the same latitude as one of the stations in the Meridional Arc. Thus the comparisons between the local variations of gravity under the continental, the coast, and the ocean stations are independent of an exact knowledge of the normal variation of gravity in proceeding from the poles to the equator. It will be seen that, without a single exception, gravity at a coast station is in excess of gravity at the corresponding inland station, and that at the ocean station it is greater than at the corresponding coast station; thus:

At Alleppy the pendulum makes		2·41	vibrations more than at	Mallapatti.
„ Mangalore	„	2·62	„	Bangalore.
„ Madras	„	2·42	„	Bangalore.
„ Cocanada	„	2·78	„	Kocundal.
„ Calcutta	„	3·19	„	Ehmadpur.
„ Minicoy	„	3·90	„	Punnæ.

(17.) I may observe that the coast stations were selected at places as far removed as possible from mountain-ranges, in order that the results might not be affected by the local variations of gravity under mountains. For this reason additional stations could not be obtained on the west coast, because to the north of Mangalore there is a range of mountains running parallel to the coast at a very short distance.

(18.) Having completed these observations, Captain Basevi returned to the head quarters at Dehra Doon last April, taking a set of observations at Kaliana *en route*, in order to ascertain whether the times of vibration of the pendulums had sensibly altered, through accident or wear of the knife-edges, in the period of four years which had elapsed since 1866, during which the apparatus had been transported (chiefly by land, but partly by sea) over a distance of several thousand miles, and the pendulum had been swung at twenty-two stations. The result indicates a slight alteration in the pendulums, probably by wear of the knife-edges, to an extent equivalent to one-third of a vibration in twenty-four hours.

(19.) It now remains for Captain Basevi to investigate the true vacuum and temperature corrections, by experiments under artificial temperatures. He is at present making the requisite preliminary arrangements for the purpose, and will commence the experiments as soon as possible. They should be completed by the time that the snows of the approaching winter are sufficiently melted to permit of the passes on the great southern ranges of the Himalayas being crossed. Captain Basevi will then proceed to take observations in the inner Himalayas, on three extensive tablelands which are of great height, and are sufficiently removed from the neighbouring ranges to obviate the necessity for minute calculations of the masses of these ranges, calculations for which the requisite data are not forthcoming. The three tablelands are "the plains of Deosai," lat. 35° 5′, long. 75° 30′, height 13,400 feet; the plains north of the Changchenmo range, lat. 35° 15′, long. 79° 20′, height 16,000 feet; and "the plains of Hanle," lat. 32° 50′, long. 79°, height 14,200 feet. Captain Basevi also proposes to take observations in the plains of the Punjab to the south of the Himalayas. Finally, he will descend the Indus, and take observations on the coast at Karachi, thus obtaining an additional coast station, which will be complementary to an inland station on Colonel Everest's Arc of the Meridian.

(20.) It does not appear necessary that any more observations than these should be taken in India. But in the proceedings of the Council of the Royal Society in which the original programme of observations was dis-

cussed, it was proposed that observations should be taken at points nearer to the equator, at Ceylon, Singapore, or Borneo; also at Aden, a position of interest, "from being in a long line of depression where a large gravitation might be expected." But as one of the two pendulums has already been swung by General Sabine at three stations on or between the equator and the parallel of Punnæ, Captain Basevi's southernmost station, and as a pendulum has been swung by Mr. Goldingham at the equator and at the Madras Observatory, which is also one of Captain Basevi's stations, I am inclined to think that there is no immediate necessity for taking observations at Ceylon, Singapore, and Borneo, and that Captain Basevi's operations need not be prolonged for this purpose. On the other hand, however, he will be easily able to observe at Aden; and he might also observe at some point in Egypt, on the plains which are crossed by the Suez Canal, with the great advantage that the stations would be complementary to certain of the stations in India; thus Aden would be compared with Madras and Bangalore, and the plains of Egypt with the Himalayan Mountains.

(21.) I propose, therefore, that Captain Basevi should proceed from Karachi to England, taking observations *en route* at Aden and in Egypt, and bringing his operations to a close by a series of observations at the Greenwich Observatory, if the Astronomer Royal has no objections. I mention the Greenwich rather than the Kew Observatory because the true time can be obtained there from the astronomical clocks, whereas at Kew it can only be obtained by observation; and if (as is probable) Captain Basevi arrives in the winter, pendulum-observations taken at Kew would be greatly delayed, as happened when the operations were commenced at Kew. Moreover, Greenwich appears to have been employed as a reference station for pendulum-observations more frequently than Kew.

J. T. WALKER, Colonel R.E.,
Supt. Great Trigonometrical Survey of India.

Preliminary Abstract of Mean Results with Pendulums Nos. 4 and 1821.

Number.	Stations.	Geodetic Coordinates. North Latitude.	Geodetic Coordinates. East Longitude.	Geodetic Coordinates. Height, in feet.	Mean Temperature.	Mean Pressure	Observed Number of Vibrations reduced to an infinitely small arc.	Corrections. Reduction to 72° F.	Corrections. Reduction to a Vacuum.	Corrected Vibrations at level of Station.	Reduction to Mean Sea-level.	Results. By Observation.	Results. By computation in terms of Punnæ ellipticity $=\frac{1}{300}$.	Computed. − Observed.
	Indian Arc Stations.	° ′	° ′		°	inches.								
1.	Punnæ	8 10	77 41	44	85·8	1·53	85971·13	+6·61	+0·44	85978·18	+0·11	85978·29		
2.	Kudankolam	8 11	77 45	166	86·2	1·46	70·83	6·76	·42	78·01	·43	78·44	85978·32	−0·12
3.	Mallapatti	9 29	78 3	343	75·5	1·23	75·91	1·68	·36	77·95	·88	78·83	79·89	+1·06
4.	Pachapolliam	11 0	77 41	999	76·3	1·82	74·99	2·05	·53	77·57	2·56	80·13	82·00	1·87
5.	S.W. end Bangalore Base	13 1	77 37	3116	72·5	3·07	72·50	0·24	·90	73·64	8·00	81·64	85·27	3·63
6.	N.E. end Bangalore Base	13 4	77 42	3007	72·9	2·04	73·61	0·42	·60	74·63	7·72	82·35	85·40	3·05
7.	Namthabad	15 6	77 36	1219	87·7	2·16	75·15	7·47	·61	83·23	3·13	86·36	89·19	2·83
8.	Kodungul	17 8	77 41	1972	81·8	2·15	80·82	4·72	·62	86·16	5·07	91·23	93·52	2·29
9.	Damargida	18 3	77 43	1934	72·4	2·79	85·20	+0·17	·82	86.19	4·97	91·16	95·64	4·48
10.	Somtana	19 5	77 42	1711	71·9	2·31	90·64	−0·05	·68	91·27	4·43	95·70	98·12	2·42
11.	Badgaon	20 44	77 39	1120	70·7	2·73	97·10	−0·60	·80	97·30	2·88	86000·18	86002·35	2·17
12.	Ehmadpur	23 36	77 43	1681	84·9	2·86	96·66	+6·14	·82	86003·62	4·38	08·00	10·34	2·34
13.	Kalianpur	24 7	77 42	1765	80·5	2·12	86001·11	4·04	·61	05·76	4·53	10·29	11·85	1·56
14.	Pahargarh	24 56	77 44	1641	76·9	3·40	03·02	2·34	1·00	06·36	4·22	10·58	14·31	3·73
15.	Usira	26 57	77 40	812	81·8	2·52	11·19	+4·68	·72	16·59	2·22	18·81	20·64	1·83
16.	Datairi	28 44	77 41	719	65·7	2·42	24·12	−3·03	·72	21·81	1·85	23·66	26·51	2·85
17.	Kaliana (1866)	29 31	77 42	826	73·7	3·54	20·41	+0·81	1·04	22.26	2·12	24·38	29·16	4·78
18.	Nojli	29 53	77 43	881	58·4	2·49	28·40	−6·47	·75	22.68	2·26	24·94	30·45	5·51
19.	Dehra	30 20	78 6	2289	61·9	2·60	22·85	−4·80	·77	18·82	5·89	24·71	31·98	7·27
20.	Mussoorie	30 28	79 12	6920	69·6	23·50	00·66	−1·16	6·93	06·43	10·23	25·67	32·42	+6·75
	Kaliana (1870)	.. ..	.. ..	....	82·7	3·67	86015·73	+5·11	+1·05	86021·89	2·12	86024·01	....	....
	Coast Stations.													
21.	Alleppy	9 30	76 20	6	80·0	1·72	85976·92	+3·81	+1·50	85981·23	0·02	85981·25	85979·90	−1·35
22.	Mangalore	12 52	74 49	7	79·7	1·43	80·13	3·70	·44	84·27	·02	84·29	85·01	+0·72
23.	Madras	13 4	80 17	27	74·4	1·82	82·71	1·16	·53	84·40	·07	84·47	85·37	+0·90
24.	Cocanada	16 56	82 18	9	78·5	1·89	89·93	3·08	·55	93·56	·02	93·58	93·09	−0·49
25.	Calcutta	22 33	88 24	18	79·9	2·15	86003·70	3·77	·62	86008·09	·05	86008·14	86007·29	−0·85
	Ocean Station.													
26.	Minicoy	8 17	73 2	6	79·7	1·91	85978·07	+3·69	+0·55	85982·31	0·02	85982·33	85978·43	−3·90
	Base Station.													
	Kew	51 28	.. ..	....	54·2	1·57	....	−8·51	....	86113·98	·05	86114·03	86113·55	−0·48

JAMES P. BASEVI, Captain R.E.,
Deputy Superintendent of Survey.