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THE ERUPTION OF KRAKATOA,

AND

SUBSEQUENT PHENOMENA.

EXPLANATORY OF COLOURED FRONTISPIECE.

These chromo-lithographs are reproduced from a series of six crayon sketches made on the bank of the Thames, a little west of London, on the evening of November 26th, 1883, by Mr. W. Ascroft, of Chelsea.

They represent the general colouring of the western sky from shortly after sunset (3h. 57m. p.m.) to the final dying out of the after-glow at about 5.15 p.m.

The increase of light after the cessation of ordinary twilight—that is to say, between Nos. 2 and 4—is very marked, and the gradual change in the tone of Nos. 3, 4, 5, and 6 very instructive.

WELLESLEY • COLLEGE

TWILIGHT AND AFTERGLOW EFFECTS AT CHELSEA, LONDON.
NOV. 26TH 1883.

Nº1. ABOUT 4·10 P.M.

Nº2. ABOUT 4·20 P.M.

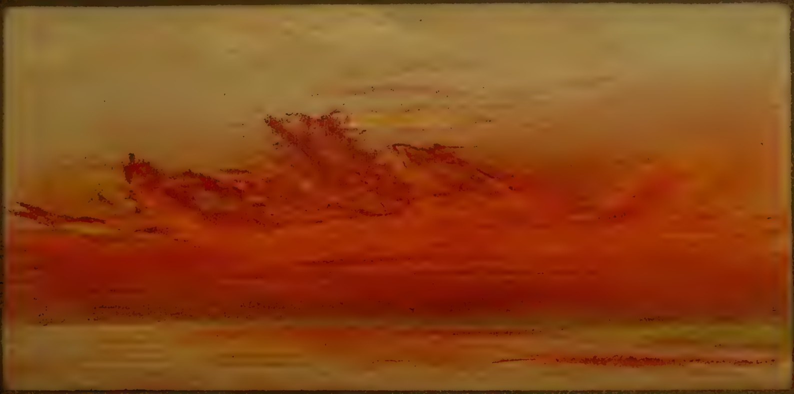
W. ASCROFT DEL.

[illegible] CO.

Nº3. ABOUT 4·30 P.M.

TWILIGHT AND AFTERGLOW EFFECTS AT CHELSEA, LONDON.
NOV. 26TH 1883.

No. 4. ABOUT 4·40 P.M.



No. 5. ABOUT 5 P.M.

W. Ascroft del. [illegible]

No. 6 ABOUT 5·15 PM

THE ERUPTION OF KRAKATOA,

AND

SUBSEQUENT PHENOMENA.

REPORT OF THE KRAKATOA COMMITTEE

OF THE

ROYAL SOCIETY.

VIZ.:—

Abercromby, The Hon. Ralph.
Archibald, E. Douglas.
Bonney, Prof. T. G., *F.R.S.*
Evans, (the late) Sir F. J., *F.R.S.*
Geikie, Dr. A., *F.R.S.*
Judd, Prof. J. W., *F.R.S.*
Lockyer, J. Norman, *F.R.S.*
Russell, The Hon. F. A. Rollo.
Scott, R. H., *F.R.S.*
Stokes, Prof. G. G., *Pres. R.S.*
Strachey, Lt.-General, *R.E., F.R.S.*
Symons, G. J., *F.R.S., Chairman.*
Wharton, Capt. W. J. L., *R.N., F.R.S.*

Edited by G. J. SYMONS, *F.R.S.*

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PREFATORY AND HISTORICAL.

The extremely violent nature of the eruption of Krakatoa on August 26th–27th, 1883, was known in England very shortly after it occurred, but it was not until a month later that the exceptional character of some of the attendant phenomena was reported. Blue and green suns were stated to have been seen in various tropical countries; then came records of peculiar haze; in November the extraordinary twilight glows in the British Isles commanded general attention, and their probable connection with Krakatoa was pointed out by various writers.

At the meeting of the Royal Society, on December 13th, a paper by Mr. Scott, and a note by General Strachey, gave the first details of the great air-wave, and indicated its nature and extent.

On January 10th, 1884, papers by Commander the Hon. F. C. P. Vereker and by Mr. Kennedy, H.B.M.'s Consul at Batavia, describing the remarkable changes in the physical configuration of the district, were read before the Royal Society. In the course of the discussion upon them, it was suggested that it would be well to collect and coördinate all the information obtainable respecting the eruption; and the President (Professor Huxley) promised that the subject should be brought before the Council.

> On January 17th, the Council passed the following resolution:—"That a "committee, to consist of Sir F. Evans, Prof. Judd, Mr. Norman "Lockyer, Mr. R. H. Scott, General Strachey, and Mr. G. J. "Symons, with power to add to their number, be appointed, to collect "the various accounts of the volcanic eruption at Krakatoa, and "attendant phenomena, in such form as shall best provide for their "preservation, and promote their usefulness."

The first meeting of the Committee was held on February 5th, all the members being present. It was resolved that a letter inviting assistance should be prepared for insertion in 'The Times' and other periodicals. The following is a copy of that letter :—

"THE KRAKATOA ERUPTION.

"Sir,—The Council of the Royal Society has appointed a committee for the purpose of collecting the various accounts of the volcanic eruption at Krakatoa, and attendant phenomena, in such form as shall best provide for their preservation and promote their usefulness. The committee invite the communication of authenticated facts respecting the fall of pumice and of dust, the position and extent of floating pumice, the date of exceptional quantities of pumice reaching various shores, observations of unusual disturbances of barometric pressure and of sea level, the presence of sulphurous vapours, the distances at which the explosions were heard, and exceptional effects of light and colour in the atmosphere. The committee will be glad to receive also copies of published papers, articles and letters bearing upon the subject. Correspondents are requested to be very particular in giving the date, exact time (stating whether Greenwich or local), and position whence all recorded facts were observed. The greatest practicable precision in all these respects is essential. All communications are to be addressed to—

"Your obedient servant,
"G. J. SYMONS,
"Chairman, Krakatoa Committee.

"Royal Society, Burlington House,
"*February* 12*th*, 1884."

A secretary also was appointed who attended daily at Burlington House for about twelve months, searching many hundred periodicals, and parts of 'Proceedings,' 'Transactions,' &c., copying out and classifying the various statements, as well as attending to the correspondence received in reply to the published invitation.

At the meeting on March 27th, 1884, a letter was read which had been received from the Royal Meteorological Society, stating that on January 16th that Society had appointed a committee to investigate the cause of the remarkable sunrises and sunsets, and had already issued circulars of inquiry over the greater part of the globe, and suggesting that therefore that branch of the inquiry should be left to them. Eventually it was arranged that all the data collected by the Royal Meteorological Society should be handed over to the Krakatoa committee, and that the members of the committee of the Royal Meteorological Society should be made members of the Krakatoa committee. The Hon. RALPH ABERCROMBY, Mr. E. DOUGLAS ARCHIBALD, and the Hon. F. A. ROLLO RUSSELL, were so elected.

Coloured drawings of the twilights were submitted to the committee on March 27th, 1884, by Mr. J. S. Dyason, and on June 19th, 1885, by Mr. W. Ascroft ; six of those submitted by the latter artist have been reproduced as a Frontispiece to this volume.

At the meeting on June 18th, 1884, Dr. Geikie, and on November 20th, 1884, Prof. Bonney, were added to the committee.

At the end of November, 1884, it was considered expedient to commence the discussion of the great mass of data collected, and it was divided into five portions, each going to a separate sub-committee as follows :—

GEOLOGICAL.

Including descriptions of the Eruption, Earthquakes, and the Geological features relating to Dust and Pumice—

Prof. Judd, Dr. Geikie,
Prof. Bonney, Mr. R. H. Scott.

METEOROLOGICAL. (A.)

Including Air-Waves, Sounds, and the geographical distribution of Dust and Pumice—

General Strachey, Prof. Stokes, Mr. R. H. Scott,

METEOROLOGICAL. (B.)

Including Twilight Effects, Coronal Appearances, Cloud Haze, Coloured Sun, Moon, &c.—

Mr. E. Douglas Archibald, Mr. J. Norman Lockyer,
Hon. Rollo Russell.

SEISMIC SEA WAVES.

Sir F. Evans (and subsequently Captain Wharton), General Strachey.

TERRESTRIAL MAGNETISM AND ELECTRICITY,

The Kew Committee.

(G. M. Whipple, B.Sc., Superintendent.)

The extraction of data being then nearly finished, it was not considered necessary to retain the services of the secretary, and all the routine work for the subsequent two years was conducted by the Chairman.

On the death of Sir F. Evans, the President and Council of the Royal Society nominated Captain Wharton as a member of the committee, and he has completed the investigation of the Seismic Sea Waves.

Thus it will be seen that 28 months elapsed between the distribution of the data to the various sub-committees and the completion of the report and its transmission to the Council. But it is to be remarked that the optical phenomena did not entirely fade from view until the early part of 1886, and that besides the great mass of material originally distributed, a constant flow of additional literature, including the very valuable report by Mr. VERBEEK, has been received and transmitted to the writers of the various Parts.

As regards the mass of material, it may be mentioned that it has included—

Barograms from	50	observatories,
Magnetograms from	11	,,
Tidal Records ,,	50	stations.

Between 300 and 400 letters have been received, most of them enclosing bulky reports. Many, being written in foreign languages, have required translation, and all have required the conversion of their local times into G.M.T., and of course the answering and forwarding of these letters has involved much clerical labour.

The printed literature on the subject has been very extensive, as is shown by the appended list of books and papers consulted, and the work altogether has been very heavy, for it has not only extended back to the year 1500, but it has ramified through many branches of physics, and has involved extensive correspondence with all parts of the globe.

In the spring of 1887 the MS. was completed and submitted to the Council of the Royal Society, together with estimates of the cost of publication. The Council, while of course expressing no opinion upon the work, authorised the committee to proceed with the printing.

I hope that I may here be permitted on behalf of the committee to acknowledge the constant and great help which we have received throughout from the President, Officers, and Council.

The volume itself will show the amount of heavy work done by the various authors, and who is responsible for the several arguments and opinions. I wish, however, to point to one unusual feature, viz., the hundreds of references which are given. The committee's first duty (and desire) was to collect facts. This duty we have all tried to discharge, and we have not only collected the facts, but have done our utmost to enable everyone to verify them.

G. J. SYMONS.

Burlington House, W., *December*, 1887.

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Parker & Coward, lith. West Newman & Co. imp.

View of Krakatoa during the Earlier Stage of the Eruption
from a Photograph taken on Sunday the 27th of May, 1883.

PART I.

ON THE VOLCANIC PHENOMENA OF THE ERUPTION, AND ON THE NATURE AND DISTRIBUTION OF THE EJECTED MATERIALS.

By Professor J. W. Judd, *F.R.S., President of the Geological Society.*

Introductory.

During the closing days of the month of August, 1883, the telegraph-cable from Batavia carried to Singapore, and thence to every part of the civilised world, the news of a terrible subterranean convulsion—one which in its destructive results to life and property, and in the startling character of the world-wide effects to which it gave rise, is perhaps without a parallel in historic times.

As is usual in such cases, the first reports of this tremendous outburst of the volcanic forces appear to have been quite misleading and altogether unworthy of credence. Nor is this to be wondered at. The towns and villages along the shores of the Sunda Strait were, during the crisis of the eruption, enveloped in a terrible darkness, which lasted for many hours, and, while thus obscured, were overwhelmed by a succession of great sea-waves; those who succeeded in saving their lives amid these appalling incidents were, it need scarcely be added, not in a position to make trustworthy observations upon the wonderful succession of phenomena occurring around them.

For some time after the eruption, the Sunda Strait was almost impassable; light-houses had been swept away, all the old familiar landmarks on the shores were obscured by a vast deposit of volcanic dust; the sea itself was encumbered with enormous masses of floating pumice, in many places of such thickness that no vessel could force its way through them; and for months after the eruption one of the has long been recognised as being at the present epoch the greatest focus of volcanic activity upon the globe. The Island of Java, with an area about equal to that of England, contains no fewer than forty-nine great volcanic mountains, some of which rise to a height of 12,000 feet above the sea-level. Of these volcanoes, more than half have been seen in eruption during the short period of the European occupation of the island, while some are in a state of almost constant activity. Hot springs, mud-volcanoes, and vapour-vents abound in Java, while earthquakes are by no means unfrequent. The chain of volcanoes which runs through the whole of Java is continued in Sumatra on the west, and in the islands of Bali, Lombok, Sumbawa, Flores, and Timor on the east.

The marked linear arrangement in this immense chain of volcanic mountains points to the existence of a great fissure in the earth's crust, along which the subterranean energy has been manifested. The Strait of Sunda, which separates Java from Sumatra, is a shallow one, having a depth of rarely more than 100 fathoms. Along the line of this Strait we have evidence of a transverse fissure crossing the main one nearly at right angles (*See* Fig. 1). Upon this transverse fissure a number of

FIG. 1.—*Sketch-map of the Sunda Strait, showing the lines of volcanic fissure which appear to traverse the district.*

volcanoes have been thrown up, namely—Pajung, in Java, with a height of 1,500 feet; the cone of Princes Island, 1,450 feet; Krakatoa, 2,623 feet; Sebesi, 2,825 feet; and Rajah Bassá, in Sumatra, 4,398 feet.

In spite of the significance of its position at the point of intersection of these two great lines of volcanic fissure, Krakatoa had, until the year 1883, attracted but little attention. Amid so many volcanoes of more striking appearance and more frequent activity, it, in fact, remained almost unnoticed.

Krakatoa does not present the regularly conical outlines characteristic of volcanoes, a form which is so well exhibited by the neighbouring island of Sebesi (*See* Fig. 2); it is, indeed, only a fragment of a great crater-ring rising out of the Sunda Strait. The general relations of the islands of the Krakatoa group and the outlines which they exhibited prior to the great eruption are illustrated by the accompanying sketch-map and section (Figs. 3 and 4, page 6).

FIG. 2.—*Sketch of the Island of Sebesi, as seen from the north-east (after Verbeek).*

By the great eruption of August, 1883, the volcano of which Krakatoa and the adjoining islands form parts was completely eviscerated. The admirable descriptions given by MM. VERBEEK and BRÉON of the splendid sections now exposed enable us not only to determine the nature of its materials, but to study all the details of the internal structure of the volcanic mass. Guided by the principles which have been established by the study of numerous volcanoes in different stages of their development, we are able from the data thus obtained to re-construct the whole history of this interesting example of volcanic architecture.

I.—SKETCH OF THE HISTORY OF THE VOLCANO OF KRAKATOA.

No principle of vulcanology is better established than that of the alternation, in the history of most volcanoes, of periods during which constant ejections take place, whereby great mountain masses, having the beautiful conical forms characteristic of Chimborazo and Fusiyama, are slowly and gradually built up, and of violent paroxysms, by which in the course of a comparatively short period, the whole centre of the great volcanic mass is blown away, and scattered in the form of scoriæ and dust; only the lowest and peripheral part being left behind in the form of a crater-ring, or "basal wreck," as Darwin so aptly called the ruins of an eviscerated volcano.

The great volcanic mountain, of which Krakatoa, Verlaten Island, Lang Island, and Polish Hat are portions of a basal wreck rising above the waters of the ocean, must have originally been one of considerable dimensions. Its circumference at what is now the sea-level could not have been much less than twenty-five miles, and its height above the same datum plane was perhaps not less than 10,000 to 12,000 feet; so that, as might have been expected from its position at the intersection of two great earth-fissures, this volcanic cone must have rivalled in its dimensions the largest among the volcanoes of the East-Indian Archipelago. The general form of the volcano at this period of its history is illustrated in Fig. 5.

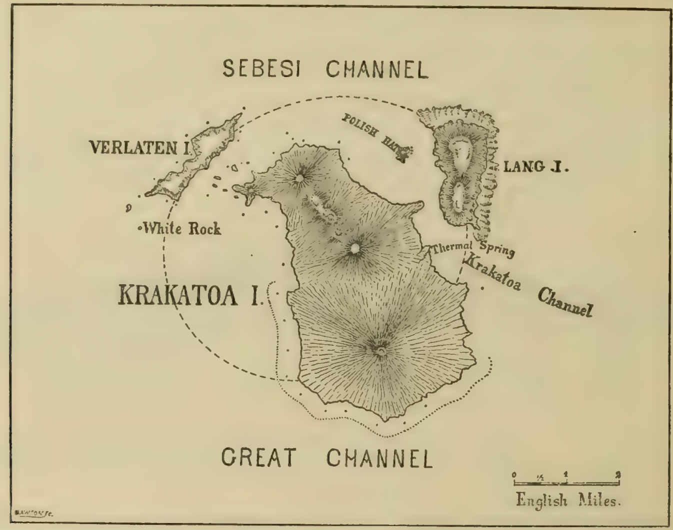

FIG. 3.—*Map of the islands of the Krakatoa Group before the eruption (from the Admiralty Chart). The nearly circular line ------- indicates approximately the submerged edge of the great crater.*

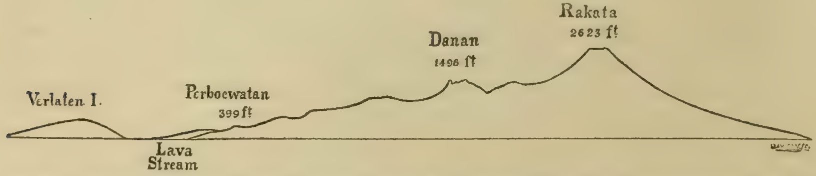

FIG. 4.—*Outline-section viewed from south-west showing the position of the volcanic cones upon the Island of Krakatoa previous to the eruption.*

That this great volcanic mountain was entirely built up by eruptions which have taken place in very recent times, geologically speaking, is shown by an interesting fact which has been ascertained by Mr. VERBEEK, namely, that beneath the mass of materials of which the volcano is composed there occur deposits of post-tertiary age, and that these in turn rest on the widely distributed tertiary rocks which are so well known in Java, Sumatra, and the adjoining islands. The original volcano, as far as can be judged by the fragments which remain of it, appears to have been almost entirely built up of lava-streams of the remarkably interesting rock known as enstatite-dacite,* consisting of the same minerals which characterise the andesitic lavas so abundant in Java and Sumatra; it nevertheless differs from the bulk of these by the higher percentage of silica which it contains. During the outwellings of these massive lavas there is scarcely any trace of explosive action on any considerable scale having taken place, and few, if any, tuffs were produced.

FIG. 5.—*Probable outlines of the Volcano of Krakatoa, at the period of its maximum dimensions.*

At some unknown period this volcano became the scene of an eruption, or series of eruptions, which, judging from the effects they have produced, must have been on even a far grander scale than that which four years ago attracted so much interest. By these outbursts the whole central mass of the volcano seems to have been blown away, and only an irregular crater-ring left behind. The great crater thus formed must have had a diameter of three or four miles, and its highest portions could have risen but a few hundreds of feet above the present level of the sea. (*See* Fig. 6, p. 8.)

The next stage in the history of the volcano consisted in the gradual filling up of the crater by a series of comparatively quiet eruptions, taking place at the bottom of the crater-ring, and building up small volcanic cones within it. By this means the crater was, to a great extent, filled up, and portions of it raised above what is now the sea-level. (*See* Fig. 7, p. 8). Whether the tract now constituting the Strait of Sunda was then dry land uniting the present islands of Java and Sumatra we have no means of determining; but I may point out that there are some grounds for believing that

* This rock has been called by many authors "enstatite-" or "hypersthene-andesite;" but although the minerals present in the rocks are the same as those found in the "enstatite-andesites" it has a silica-percentage of over 70, and it, therefore, belongs to the class of acid lavas. It bears, in fact, the same relation to the andesites that the rhyolites do to the trachytes, and on this account the name "dacite" may be conveniently applied to it.

the formation of the depression occupied by the straits was subsequent to the evisceration of the volcano.

In a great number of cases it has been shown that the piling up of materials upon a portion of the earth's crust to form volcanic mountains is accompanied or followed by a depression of the surface, so that the strata all round the volcano acquire a downward dip towards the centre of eruption.* The cause of this depression of the volcanic mass appears to be twofold—*first*, the removal of the support afforded by the vast masses of material removed from below the vent during eruptions; and, *secondly*, the weight of the gradually increasing mountain-mass which rests on the flexible crust. It seems not improbable that the depression between the islands of Java and Sumatra may have resulted from subsidences accompanying or following the ejections taking place at the great central volcanic focus of Krakatoa.

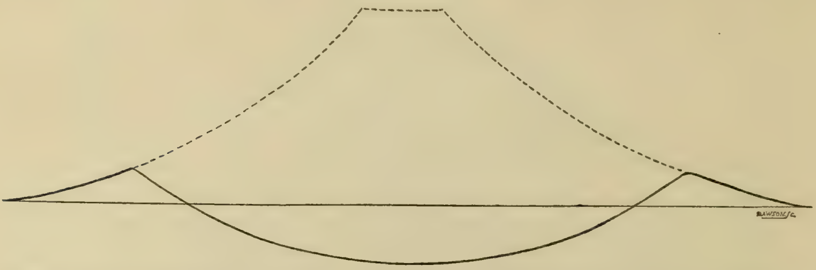

FIG. 6.—*Probable outlines of the great crater-ring ("basal wreck") of the Krakatoa Volcano, after the ancient paroxysmal outbursts. The dotted line indicates the mass which was blown away.*

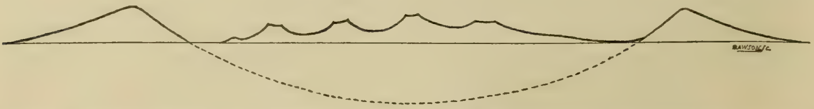

FIG. 7.—*Probable outlines of the Krakatoa Volcano after the great crater indicated by the dotted line had been filled up by the growth of numerous small cones within it.*

Subsequently to the partial in-filling of the great crater, a lateral or parasitical eruption seems to have taken place on the southern edge of the great crater-ring, and this outburst is remarkable for a very striking change in the nature of the materials ejected. The materials forming the cones inside the crater-ring were composed of materials similar to that of the latter itself, namely, the lava known as enstatite-dacite, but the new parasitical cone was built up of basaltic lavas and scoriæ. The ejections from this lateral vent must have been abundant and long-continued, for they

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* Darwin, 'Volcanic Islands,' p. 9; Heaphy, 'Quart. Journ. Geol. Soc.,' vol. xvi. (1860), p. 244; Scrope, 'Volcanoes,' 2nd ed. (1872), p. 225; and the author, 'Quart. Journ. Geol. Soc.,' vol. xxx. (1874), p. 257.

resulted in the piling up of a cone which, standing on the edge of the old crater-ring, rose to the height of 2,623 feet above the sea. (Fig. 8.)

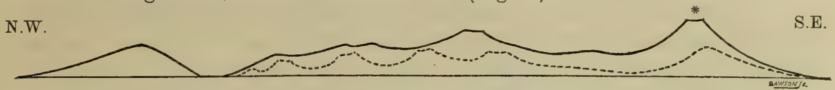

FIG. 8.—*Form of Krakatoa in historical times, after the formation of the great lateral cone of Rakata,* and the growth of other cones within the great crater.*

It was this conspicuous basaltic cinder-cone that was called by the natives the peak of Rakata, which in the old Kawi or Javanese language signifies a crab. The name, under the Dutch form, Krakatau, the Portuguese Krakatão, and the English Krakatoa, has been extended to the whole island on which this striking cinder-cone stood. It is convenient to employ the same name also for the entire volcano of which this island constitutes the largest part rising above the ocean.

Amid the numerous, lofty, and strikingly conical volcanic mountains of this district, the insignificant masses of Krakatoa and its neighbouring islets naturally attracted but little attention. The early voyagers in these seas describe the four small islands of the group, like the others in the Strait, as being clothed with the most luxuriant vegetation, and as affording a wonderful relief to eyes long accustomed to the monotony of a waste of waters. None of the islands of the Krakatoa group appears to have had at any time permanent inhabitants. The natives living in the towns and villages along the shores of the Strait merely visited the islands from time to time, in order to collect the produce of the magnificent forests which covered them; while the anchorages and places of shelter around their shores were resorted to by the native fishermen. Consequently, while hundreds of vessels every year passed within a short distance of these remarkable islands, the characters of their interior remained almost unknown; indeed, such phenomena as the outburst of hot springs and the occurrence of earthquake-shocks might, and probably did, occur without attracting attention, although the outbreak of any considerable volcanic eruption would have given rise to steam-clouds that could not fail to attract the attention of those on board passing vessels.

Unfortunately, neither the Dutch nor the English charts give any very exact details concerning the forms and contours of the islands. The two great channels to the north and south of the Krakatoa-group were carefully sounded, but of the islands themselves we have only the outlines rudely laid down (and these differ very greatly in the several published charts), with sketches of their form as seen from ships, and indications of their heights above the sea-level. A sketch of the island of Krakatoa was made by P. J. BUIJSKES, the captain of a Dutch man-of-war, in 1849, and another drawing of the islands of the group by Mr. VERBEEK in 1880. The English chart, with sketches of some of the islands as seen from the sea, was made in 1854, and the Dutch chart in 1874; but additions and corrections to both these charts were made from time to time by the surveying officers of both navies Nothing, however, in the shape either of a complete topographical or of a geological survey of the islands was ever undertaken; and the absence of the information which would have been afforded by such surveys, is very seriously felt in all attempts to estimate the exact nature and amount of the changes wrought by the late eruption.

From all the information available, it appears that Krakatoa consisted of the regular basaltic cone known as Rakata, rising from the southern end of the island to the height of 2,623 feet, and having a small depression, probably marking a crater, at its summit. The northern part of the island seems to have consisted of a number of more or less regularly conical masses, two of which only had received distinct names. Near the centre of the island was the cone called Danan, and this, or a neighbouring peak, had a height of 1,496 feet, and is said to have had a crater at its top; at the northern end of Krakatoa was the smaller cone called Perboewatan, with a height of 399 feet, having a crater breached on its western side, from which a stream of very glassy enstatite-dacite lava descended to the sea-level. Verlaten and Lang Islands were isolated portions of the old crater-ring, and rose to only a moderate elevation above the sea-level, while Polish Hat formed part of the masses ejected within the crater. (*See* Figs. 3 and 4, p. 6.)

The native traditions collected by M. Bréon point to the conclusion that eruptions had taken place at Krakatoa during the time that the district had been inhabited by the Malayan tribes. Authentic history in this case, however, commences only about three centuries ago.

In May, 1680, an eruption appears to have broken out at Krakatoa, of which we have unfortunately only very meagre accounts in the writings of Vogel and Hesse. Great earthquakes are said to have been felt in the neighbourhood, and vast quantities of pumice to have been ejected, which covered all the surrounding seas. The eruption seems to have continued with little intermission till the November of the following year, and to have destroyed the rich tropical forests that covered the island. Which of the volcanic cones composing Krakatoa was then in eruption is not certainly known, but it may be plausibly conjectured that it was Perboewatan, upon the slopes of which conspicuous and very fresh lava-streams of enstatite-dacite are recorded as being seen by several later authors. The eruption at this time seems to have been of the continual moderate character by the repetition of which the small cones occupying the greater part of Krakatoa, and filling up the vast submerged crater, had been formed.

From the effects of this outburst, however, Krakatoa soon recovered, and the event seems to have been so far forgotten that doubts have even been expressed as to the accuracy of the narratives recording it. For these doubts there do not seem to be any very good reasons. The rich vegetation which clothed the island made the inhabitants of the neighbouring shores and the passers in ships forget the terrible forces which were slumbering beneath a scene of so much beauty. Some, however, who landed on the island and made their way into the almost impenetrable forests declared that they had met with hot springs, and one such spring is indicated on the Admiralty chart of the island.

Six or seven years ago it became evident that the volcanic forces, which for nearly two centuries had remained dormant beneath the Sunda Strait, were once more awakening into activity. Earthquakes were of frequent occurrence, and during one of these, on September the 1st, 1880, the lighthouse on Java's First Point was seriously injured. These earthquakes were felt as far away as North Australia.

On the morning of Sunday, May the 20th, 1883, booming sounds like the firing of artillery were heard at Batavia and Buitenzorg, which towns are situated nearly 100 English miles from Krakatoa, and for many hours a rattling of the doors and windows was maintained in these towns and in all the neighbouring villages; on board a mail-steamer passing through the Strait, it was noticed that the compass-needles were violently agitated.

On the morning of May the 21st a sprinkling of ashes was noticed to fall at Telok Betong and Semanka, on one side of the Strait, and at Buitenzorg and the mountains around that place on the other. But it was not till the evening of the same day that a steam-column, issuing from Krakatoa, revealed to the inhabitants of the district the true locality of the disturbance which had been going on for two days. On the 22nd of May, at 8 p.m., the captain of a vessel passing close to Krakatoa was able to see that the dome-shaped mass of vapour issued from the lower parts of the island, and not from the top of the peak of Rakata; a succession of fiery flashes, each followed by a loud explosion, accompanied the discharge of fragments of pumice and dust into the atmosphere, while vivid flashes of lightning were seen playing around the vapour-column. Much of the pumice and dust fell beyond the limits of the island, and on May the 23rd a ship encountered a large quantity of this pumice off Flat Cape, in Sumatra, which was found to increase in amount until Krakatoa was passed. The pumice was then floating out into the Indian Ocean.

It is evident from these accounts that Krakatoa had re-entered on a phase of moderate (Strombolian) activity, similar to that which it had exhibited for some months during the years 1680 and 1681. That the outburst was one of considerable violence, however, especially at its commencement, was shown by the fact that the commander of the German war-vessel, *Elisabeth*, estimated the height of the dust-column issuing from the volcano as 11 kilometres (36,000 feet, or 7 miles); and falls of dust were noticed at the distance of 300 miles.

Mr. H. O. Forbes, then resident at Timor, 1,350 English miles distant, relates that on May the 24th a small quantity of greyish dust fell there; but it is possible that this may have come from some other and much nearer volcano than Krakatoa.

It seems that the eruption, which was so violent at its first outburst, soon became of a more moderate character—so much so, indeed, that the residents in Batavia and other portions of the surrounding district, who are accustomed to hearing of earthquakes and volcanoes in their vicinity, soon ceased to pay much attention to the subject. Mr. VERBEEK has, however, collected from the lighthouse-keepers on the shores of the Strait, and from the captains of the mail-steamers and other passing vessels, many very interesting details of this preliminary outbreak.

On May the 26th an excursion party was formed at Batavia, and proceeded in a steam-vessel to the scene of the eruption. They reached the volcano on the Sunday morning, May the 27th, after witnessing, during the night, several tolerably strong explosions, which were accompanied by earthquake-shocks. Krakatoa and the adjoining islands were seen to be covered with fine white dust like snow, while the trees on the northern parts of Krakatoa and Verlaten Islands had been, to a great extent, deprived of their leaves and branches by falling pumice—a fate which those on Lang Island and Polish Hat, as well as on the Peak of Rakata, had to a great extent escaped.

It was then seen that it was the cone of Perboewatan which was in activity—explosions occurring at intervals of from 5 to 10 minutes, and each of these explosions being attended with the uncovering of the liquid lava in the vent, whereby the overhanging steam-cloud was lighted up and glowed for a few seconds. The column of vapour was estimated as rising to a height of less than 10,000 feet, and the fragments of pumice as being shot to the height of about 600 feet. It appears from these accounts that the violence of the eruption had somewhat diminished since the first detonations, which were heard so far off and were accompanied by so lofty a vapour-cloud. From some of the accounts, however, it appears that certain of the explosions were of exceptional violence, and that pieces of pumice were thrown to very great heights in the atmosphere; for it is said that they were caught by the upper currents of the air and carried away in a direction opposite to that towards which the wind was blowing at the time. The noise made by the explosions and the hurtling of the ejected fragments in the air, is said to have been so great that when a rifle was discharged its sound might be compared to "the popping of a champagne-cork amid the hubbub of a banquet."

Ascending ankle-deep in loose pumice over the slopes of the low depressed cone of Perboewatan, which was found to have a height of something over 300 feet above the sea, the visitors to the island found at the top a large crater 3,000 feet in diameter, and sloping down to a flat bottom which had about one-half that diameter, and was covered with a black crust. The crater-floor, which was about 150 feet from the upper edge, showed in its centre a cavity about 150 feet in diameter, from which the great steam-column issued with a terrific sound. The western side of the crater was seen to be breached by the obsidian lava-stream descending to the sea. It is conjectured that this was formed in 1680-81.

The material ejected was pumice with fragments of black glass; it is described by some as containing crystals of plagioclase felspar, pyroxene and magnetite. A specimen brought away by one of the visitors was, however, given to Mr. H. O. FORBES, and by him brought to England; and this specimen, which was handed to me by that gentleman, proved to be of a somewhat peculiar character and quite different from most of the pumice ejected during the later stages of the eruption, as will be shown in the sequel.

A photographer on board the steamer succeeded in obtaining a satisfactory view of the eruption at that time, and this photograph, which was coloured by an eye-witness of the eruption, is reproduced in Plate I.

After the period of this visit, although there was no intermission in the eruption, there appeared to be a decline in the volcanic activity, as far as can be judged from the reports obtained from the lighthouses of the Strait, and from the captains of passing vessels. It was ascertained at Anjer on June the 19th, that the height of the vapour-column and the force of the explosions were again increasing; and on the 24th of the same month it was distinctly noticed that a second column of vapour was ascending from the centre of the island. At Katimbang, from which place the Island of Krakatoa can be seen, it was noticed that the appearance of Perboewatan had entirely changed; the conspicuous summit had disappeared, having probably been blown away during the enlarging and deepening of the crater.

During the month of July, the eruption from the two points in the island was observed and described, both by witnesses on the shores and by others on vessels making the passage of the Strait. Some detonations of exceptional violence, and several small earthquakes, were from time to time recorded alike from the Java and Sumatra shores; but in a district where earthquakes and volcanic outbursts are so frequent, this eruption of Krakatoa during the summer months of 1883 seems to have been regarded as nothing more than a nine-days' wonder, and soon ceased to attract any particular attention.

On August the 11th, however, the island was visited by Captain FERZENAAR, the chief of the topographical staff of Bantam. Sailing along the north-east side of the island in a native boat he was able to make a sketch of that part of the island, the heavy masses of vapour and dust driven by the wind preventing him from examining the other portions of the island. By this time the forests of the whole of Krakatoa appear to have been completely destroyed, only a few trunks of trees being left standing above the thick covering of pumice and dust. This mantle of dust near the shores was found to be 20 inches in thickness.

Three large vapour-columns were seen ascending and carrying up immense clouds of dust and pumice from as many craters, one of these being the original crater of Perboewatan, while the other two were in the centre of the island. Of the latter, one was probably the original crater of Danan, enlarged and deepened by the explosive action so as to diminish the height of the cone, while the other crater seems to have been opened at the northern foot of Danan. But besides these three principal craters no fewer than eleven other foci of eruption could be observed on the visible portions of the island, from which smaller steam-columns issued and ejections of dust took place.

It is evident, therefore, that at this period the activity of the volcanic forces in the island had increased in a remarkable manner, and that from all portions of the lower-lying parts of the island situated to the north of the Peak of Rakata, that is from the area within the walls of the original crater, outbursts were going on. This account of the state of the volcano on August the 11th is very interesting indeed, as being the last which we have before the great paroxysm which occurred towards the end of the same month.

The vessels which passed close to Krakatoa between the 11th of August and the time of the great catastrophe reported a heavy rain of pumice and dust and constant loud explosions as taking place. On the 25th the dust had been carried to such a height as to begin to fall at Telok Betong, nearly fifty miles distant.

The eruption which began on May the 20th, and culminated in the tremendous explosion of August the 27th, thus appears to have exhibited the following vicissitudes:—Bursting out with somewhat sudden violence, the eruption from Perboewatan seems to have had sufficient force to carry the volcanic dust to various points along the shores of Java and Sumatra. After this sudden outburst, there was a rapid and marked decline in violence, and then a gradual increase till June the 24th, when a second crater had opened in the centre of the island. The eruptive force still increasing, a third crater made its appearance, and innumerable smaller vents were originated all over the surface of the filled-up crater of the great volcano. From this time the activity seemed still constantly to increase, till its grand culmination on the 27th of August.

The Eruption of August 26th and 27th, 1883.

On the afternoon of the 26th of August, and through the succeeding night and day till the early morning of the 28th of August, it was evident that the long-continued moderate eruptions (Strombolian stage) which had for some days been growing in intensity, had passed into the paroxysmal (Vesuvian) stage. In order to weigh the evidence which we have concerning the nature of this critical and most interesting period of the eruption of Krakatoa, it may be well to consider what were the facilities for observation possessed by the several individuals from whom the reports concerning the eruptions were obtained.

Situated respectively at a distance of 94 and 100 English miles to the east of Krakatoa are the two important towns of Batavia and Buitenzorg. In both these places, numerous Europeans capable of making accurate observations were resident; there were also self-recording instruments, the tracings of which have proved of the greatest value in these enquiries. At numerous small towns and villages along the Javan and Sumatran coasts of the Strait of Sunda, and in the five lighthouses, two of which were destroyed, European officials were located. Many of these fled during the terrible night of the 26th of August, and others were drowned by the great sea-waves which submerged all the coast-towns on the morning of the 27th. Very admirably has Mr. Verbeek collected and discussed the reports made by the officials of the coast-towns and villages who survived that night of horrors.

Perhaps, however, the most important evidence of what was actually going on at Krakatoa during the crisis of the eruption is that derived from witnesses on board ships which sailed between Java and Sumatra while the great outburst was in progress, or those that were at the time in the immediate vicinity of either the eastern or western entrance of the Sunda Strait. From many more distant points, however, valuable confirmatory or supplementary evidence has been obtained, for which we are indebted to the captains or passengers of vessels passing through the eastern seas during that period.

Only three European ships appear to have been actually within the Sunda Strait during the height of the eruption on the night of the 26th of August and the early morning of the 27th, and to have escaped destruction, so that those on board could tell the tale of what they witnessed.

The greatest opportunities for observation seem to have been those which were afforded to Captain Watson of the British ship *Charles Bal*, then on its voyage to Hong Kong. This vessel passed Princes Island at 9 a.m. on Sunday the 26th of August; at noon she was on the south-west side of Krakatoa; and at 4.15 p.m. she reached a point nearly due south of the volcano, and about 10 miles distant from it. The darkness being too great to permit of safe navigation, sail was shortened, and through the whole night the vessel was kept beating about on the east of the volcano, and within a dozen miles from it. At 6 a.m. on the 27th, the Java shore was sighted, and the vessel was enabled to continue her voyage.

The Batavian steamship *Gouverneur-Generaal Loudon*, Commandant T. H. Lindeman, left Batavia on the morning of the 26th of August, and reached Anjer at 2 p.m. the same day. Leaving that port at 2.45 p.m., she sailed for Telok Betong, taking a number of coolies and women as passengers, and passing about 30 miles north of Krakatoa, reached her destination at 7.30 p.m. Finding at midnight that it was impossible, on account of the storm which was raging, to communicate with the shore, the vessel steamed out into the bay and anchored. She thus escaped being stranded by the great sea-waves of the early morning, like the unfortunate Government steamer *Berouw*, which was at this time anchored close to the pier-head at Telok Betong. At 7 30 a.m. on the 27th, the steamer *G. G. Loudon* started to return to Anjer, but had to come to anchor at 10 o'clock on account of the rain of pumice, and the storm that was raging. During Tuesday, the 28th, she steamed round the west and south sides of Krakatoa, called at the part of the coast where Anjer formerly stood, and then proceeded to Batavia.

The Dutch barque *Marie*, engaged in the salt-trade, was, during the whole time of the eruption, anchored off Telok Betong. On the morning of the 27th of August, thanks to the precaution of putting out a third anchor, she rode safely, and was able to avoid being stranded by the gigantic sea-waves, which swept on to the land the Government steamer *Berouw*, three schooners, and many smaller craft lying off the same port. The vessel appears to have been at times in imminent danger, but only four of the persons on board of her were drowned.

During the whole of Sunday, the 26th of August, two vessels, the barque *Norham Castle*, Captain O. SAMPSON, and the ship *Sir Robert Sale*, Captain W. T. WOOLDRIDGE, were at the eastern entrance of the Strait, and about 40 miles from Krakatoa. On the morning of Monday, the 27th, both these vessels entered the Strait, but owing to the darkness, neither made much progress till the morning of the 28th, when, falling in with each other, they made their way in company, but with much difficulty, through the Strait.

The Dutch hopper-barge, *Tegal*, which sailed from Batavia for Merak early on Monday, the 27th of August, remained at anchor near the eastern entrance of the Strait during the great darkness, but on Tuesday, the 28th, entered the Strait.

On the morning of Sunday, the 26th of August, the ship *Berbice*, of Greenock, Captain WILLIAM LOGAN, was at the western entrance of Sunda Strait, and about 40 miles from Krakatoa. This vessel remained beating about the entrance till Wednesday, the 29th, when she was able to sail through the Strait.

These are the vessels which, during the crisis of the great eruption, were in the most favourable positions for those on board of them to make observations concerning what was taking place at Krakatoa. The approximate positions of these vessels are shown in the accompanying chart (Fig. 9). Let us now turn our attention to some other vessels which were at greater distances from the scene of eruption, but, from the captains or passengers on board which, valuable information has been received.

The Norwegian barque *Borjild*, Captain AMUNDSEN, was at anchor near Great Kombuis Island, 75 miles east-by-north of Krakatoa, during the 26th and 27th of August.

The British ship *Medea*, Captain THOMSON, was, at 2 p.m. on the 26th, in the vicinity of the last-mentioned vessel, and sailing eastward came to anchor about 89 miles from Krakatoa.

The American barque *William H. Besse*, Captain BAKER, on its way from Manilla to Boston, U.S.A., having called at Batavia, was in the same neighbourhood, and on Wednesday, 29th, and Thursday, 30th of August, was passing through the Strait.

The British steamer *Anerley*, Captain STRACHAN, bound from Singapore to Mauritius, was, on the 26th of August, in Banca Strait, 250 English miles north of Krakatoa. During the 27th the steamer remained at anchor near North Watcher Island, 92 English miles north-east of the volcano.

The Siamese barque *Thoon Kramoom*, Captain ANDERSEN, bound from Bankok to Falmouth, lay, on the 27th and 28th of August, in the Strait of Banca, 230 English miles north of Krakatoa, and, sailing southwards, passed through the Strait of Sunda on the 31st of August.

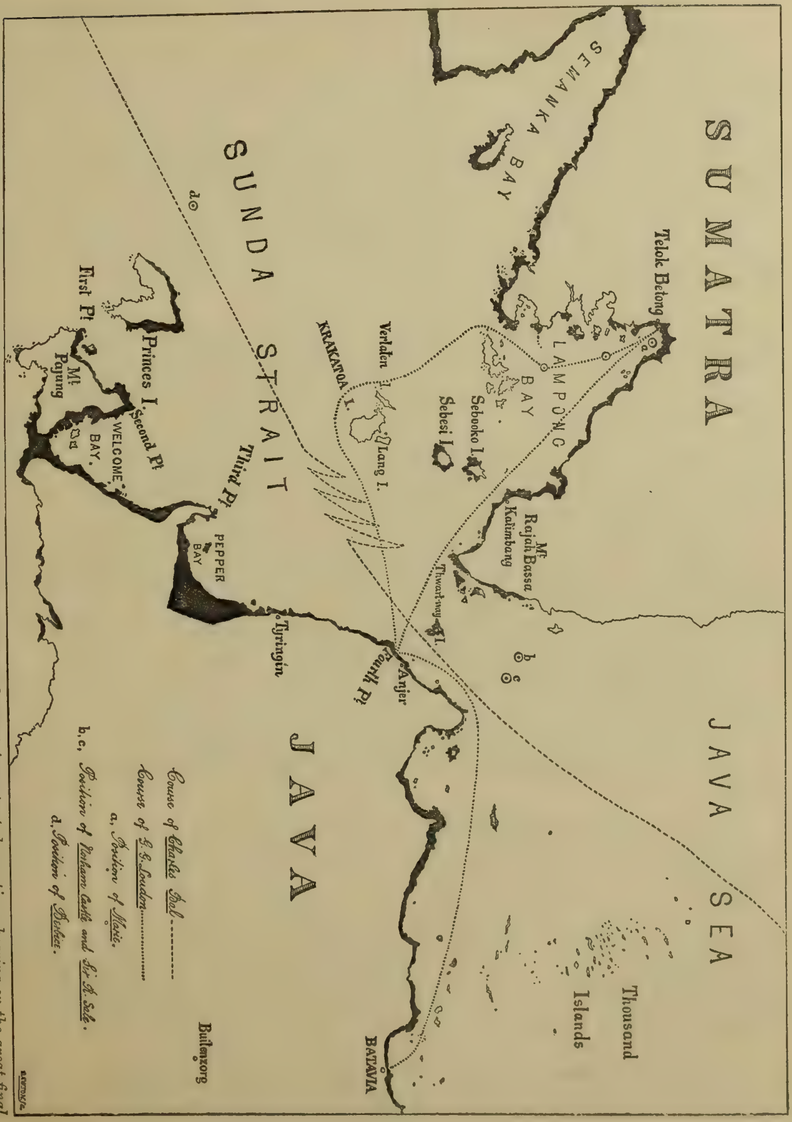

Fig. 9.—*Chart to illustrate the positions of the towns and the tracks of the vessels where the most important observations bearing on the great final outburst at Krakatoa were made. The areas shaded black are those which were submerged by the great sea-waves.*

Several vessels, among which was the barque *Hope*, were lying in Batavia Bay during the great paroxysmal outburst.

The mail steamer *Prinses Wilhelmina*, which passed through the Strait on the 23rd of August, coming from the west, remained at anchor at Batavia during the time of the great eruption.

Among vessels which were at still greater distances from the volcano during the time of the great outburst, the following may be mentioned as those from which information and specimens of the falling pumice and dust have been received :—

The British ship *Bay of Naples*, Captain TIDMARSH, was, during the eruption, about 138 English miles south of Java's First Point, and the barque *Lucia* was about 300 miles to the south-east of Krakatoa.

From the seas to the west of the Strait of Sunda we have information from the steamship *Simla*, Captain M. NICHOLSON, where dust, falling at a distance of about 1,150 English miles from the volcano, was collected, and from the barque *Jonc*, Captain L. REID, at about 600 English miles from the Strait. On board the British ships *Earl of Beaconsfield*, and the *Ardgowan*, Captain ISBISTER, and the German brig *Catherine*, dust fell when they were between 900 and 1,100 English miles from Krakatoa ; and on board the British barque *Arabella*, Captain WILLIAMS, when about 1,100 English miles from Krakatoa.

The mail steamer *Prins Frederik*, on its way to Holland, passed near Krakatoa on the 25th of August, and the steamer *Batavia* sailed from Padang to Vlakke Hoek on the evening of the 27th.

The *Prins Hendrik*, a Dutch man-of-war, was ordered to the Strait of Sunda immediately after the eruption, in order to succour the survivors.

H.M.S. *Magpie*, Commander the Hon. F. C. P. VEREKER, was at Sandakang, N. Borneo, at the time of the eruption, and on the 18th of October visited the Strait for the purpose of examining the changes which had taken place. Somewhat later H.M.S. *Merlin*, Commander R. C. BRUNTON, visited the locality, and sent in a report to the Admiralty.

From various ports, accounts have been received, sent by British Consuls and by residents, and many of these have proved to be of great service to the Krakatoa Committee.

The log-books of the different vessels mentioned, and narratives written by the captains and passengers on board of them, taken in conjunction with the reports collected with so much care by Mr. VERBEEK, have afforded the means of compiling the following account of what occurred at Krakatoa during Sunday, the 26th, and Monday, the 27th, August.

The vessels passing through the Strait, as well as the observers on land, all reported a very marked though gradual increase in the violence of the eruption during the three days which preceded Sunday, the 26th of August.

On that day, about 1 p.m., the detonations caused by the explosive action attained such violence as to be heard at Batavia and Buitenzorg, about 100 English miles away.

At 2 p.m. Captain THOMSON, of the *Medea*, then sailing at a point 76 English miles E.N.E. of Krakatoa, saw "a black mass rising up like a smoke, in clouds," to an altitude which has been estimated as being no less than 17 miles. If this estimate be correct, some idea of the violence of the outburst can be formed from the fact that during the eruption of Vesuvius in 1872 the column of steam and dust was propelled to the height of from only 4 to 5 miles.

The great detonations at this time were said to be taking place at intervals of about ten minutes.

By 3 p.m. the sounds produced by the explosions at Krakatoa had so far increased in loudness that they were heard at Bandong and other places 150 miles away; and at 5 p.m. they had become so tremendous that they were heard all over the island of Java, and at many other equally distant localities. At Batavia and Buitenzorg they were, during the whole night, so violent that few people in the district were able to sleep; the noise is described as being like the discharge of artillery close at hand, and as causing rattling of the windows and shaking of pictures, chandeliers, and other hanging bodies. Nearly all observers agree that there was nothing in the nature of earthquake-shocks, but only strong air-vibrations.

Captain WATSON, of the *Charles Bal*, who was only 10 miles south of the volcano during this Sunday afternoon, describes the island as being covered with a dense black cloud; "clouds or something were being propelled from the north-east point with great velocity;" sounds like discharges of artillery at intervals of a second of time, and a crackling noise, probably due to the impact of fragments in the atmosphere, were heard; the whole commotion increasing towards 5 p.m., when it became so intense that the Captain feared to continue his voyage, and began to shorten sail. From 5 to 6 p.m. a rain of pumice in large pieces, quite warm, fell upon the ship.

Captain WOOLDRIDGE, of the *Sir R. Sale*, viewing the volcano from the north-east at sunset on Sunday evening, the 26th, describes the sky as presenting "a most terrible appearance, the dense mass of clouds being covered with a murky tinge, with fierce flashes of lightning." At 7 p.m., when the dense vapour and dust-clouds rendered it intensely dark, the whole scene was lighted up from time to time by the electrical discharges, and at one time the cloud above the mountain presented "the appearance of an immense pine-tree, with the stem and branches formed with volcanic lightning." The air was loaded with excessively fine ashes, and there was a strong sulphurous smell. Captain O. SAMPSON, of the *Norham Castle*, who was in the same neighbourhood, gives a similar account of what he witnessed. The steamer *G. G. Loudon* passed to the north-west and west of the volcano, within a distance of 20 or 30 miles; it was seen to be "casting forth enormous columns of smoke," and the vessel passed through "a rain of ashes and small bits of stone."

During the night, while the *Charles Bal* remained beating about on the east of Krakatoa, and within about a dozen miles of the island, Captain WATSON records the phenomena of "chains of fire, appearing to ascend" between the volcano and the sky, while on the south-west side there seemed to be "a continual roll of balls of white fire." These appearances were doubtless caused by the discharge of white-hot fragments of lava, and their roll down the sides of the peak of Rakata, which was still standing.

The air at this distance, though the wind was strong at the time, was described by Captain WATSON as being "hot and choking, sulphurous, with a smell as of burning cinders;" masses like "iron-cinders" fell on the ship, and the lead from a bottom of 30 fathoms came up quite warm. From midnight till 4 a.m. explosions continually took place, "the sky, one second intense blackness, the next a blaze of fire."

All these details prove conclusively that Krakatoa had arrived at the paroxysmal phase of eruption. The explosive bursts of vapour beginning on the afternoon of Sunday and continuing at intervals of ten minutes, increased in violence and rapidity, and from sunset till midnight there was an almost continuous roar, which moderated a little towards early morning. Each explosive outburst of steam would have the effect of removing the accumulating pumice from the surface of the melted lava, by blowing it into the atmosphere, and the cauldron of white-hot lava would then have its glowing surface reflected in the clouds of vapour and dust hanging above.

The numerous vents on the low-lying parts of Krakatoa, which were recorded as having been seen by Captain FERZENAAR on the 11th of August, had, doubtless, by this time become more or less united, and the original crater of the old volcano was being rapidly emptied by the great paroxysmal explosions which commenced in the afternoon of the 26th of August.

All the eye-witnesses are in agreement as to the splendour of the electrical phenomena displayed during this paroxysmal outburst. Captain WOOLDRIDGE, viewing the eruption in the afternoon from a distance of 40 miles, speaks of the great vapour-cloud looking like "an immense wall with bursts of forked lightning at times like large serpents rushing through the air." After sunset this dark wall resembled a "blood-red curtain, with the edges of all shades of yellow; the whole of a murky tinge, with fierce flashes of lightning." Captain O. SAMPSON, viewing the volcano from a similar position at the same time, states that Krakatoa "appeared to be alight with flickering flames rising behind a dense black cloud; at the same time balls of fire rested on the mastheads and extremities of the yard-arms."

Captain WATSON states that during the night the mastheads and yard-arms of his ship were "studded with *corposants*," and records the occurrence of "a peculiar pinky flame coming from clouds which seemed to touch the mastheads and yard-arms." From the *G. G. Loudon*, lying in the Bay of Lampong, 40 or 50 English miles north-west of the volcano, it was recorded that "the lightning struck the mainmast-conductor five or six times," and that "the mud-rain which covered the masts, rigging, and decks, was phosphorescent, and on the rigging presented the appearance of St. Elmo's fire. The natives engaged themselves busily in putting this phosphorescent light out with their hands, and were so intent on this occupation that the stokers left the engine-rooms for the purpose, so that the European engineers were left to drive the machinery for themselves. The natives pleaded that if this phosphorescent light, or any portion of it, found its way below, a hole would burst in the ship; not that they feared the ship taking fire, but they thought the light was the work of evil spirits, and that if the ill-omened light found its way below, the evil spirits would triumph in their design to scuttle the ship."

This abundant generation of atmospheric electricity is a familiar phenomenon in all volcanic eruptions on a grand scale. The steam-jets rushing through the orifices of the earth's crust constitute an enormous hydro-electric engine; and the friction of ejected materials striking against one another in their ascent and descent also does much in the way of generating electricity.

Up to late in the afternoon of the 26th of August, the phenomena exhibited by Krakatoa were precisely similar to those witnessed at every great paroxysmal volcanic eruption. But at that time the effects of the somewhat peculiar position of the Krakatoa crater began to be apparent. Lying as it does so close to the sea-level, the work of evisceration by explosive action could not go far without the waters of the ocean finding their way into the heated mass of lava from which the eruption was taking place.

It is often assumed that if a mass of water come into contact with molten lava a terrible outburst of steam, producing a great volcanic eruption, must be the consequence, and some vulcanologists insist that the admission of water by fissures into subterranean reservoirs of lava is the determining cause of all volcanic outbreaks. But careful observation does not give much countenance to this view. Lava-streams have frequently been seen to flow into the sea, and although a considerable generation of steam occurred when the molten mass first came in contact with the water, yet none of the prolonged effects which are popularly supposed to result from the conflict of fire and water were found to occur. The surface of the lava-current becoming rapidly chilled, a layer of slowly conducting rock is formed at its surface, and then the gradual cooling down of the whole mass ensues, without further disturbance.

By the lowering of the mass lying within the old crater-ring of Krakatoa, and the diminution in height of the crater-walls, water would from time to time find a way to the molten lava below; each such influx of water would no doubt lead to the generation of some steam with explosive violence, and the production of small sea-waves which would travel outwards from Krakatoa as a centre. From the reports made by the officials at Anjer and other places on the shores of Java and Sumatra, the production of such waves, which were only a few feet in height, began to be observed about 5.30 p.m. on Sunday, the 26th of August, and continued at irregular intervals all through the night. Towards morning, however, the chilling effects of the water which had from time to time found its way to the molten materials below the volcano began to be felt, and as a result a diminution in the activity of the volcano is recorded.

If, as I shall show when I proceed to discuss the nature of the materials ejected from Krakatoa, the cause of the eruptive action was due to the disengagement of volatile substances *actually contained in those materials*, the checking of the activity, by the influx into the molten mass of vast quantities of cold sea water, would have the same effect as fastening down the safety-valve of a steam-boiler, while the fires below were maintained in full activity.

The constant augmentation of tension beneath Krakatoa, in the end gave rise to a series of tremendous explosions, on a far grander scale than those resulting directly from the influx of the sea-water into the vent; the four principal of these occurred, according to the careful investigations of Mr. VERBEEK, at 5.30, 6.44, 10.2,* and 10.52, Krakatoa time, on the morning of August the 27th. Of these, the third, occurring shortly after 10 o'clock, was by far the most violent, and was productive of the most wide-spread results.

Although no one was near enough to Krakatoa during these paroxysmal outbursts to witness what took place there, a comparison of the condition of the volcano and of the surrounding seas before and after these terrible manifestations of the subterranean forces, leaves little doubt as to the real nature of the action.

In the first place, we find that the whole of the northern and lower portion of the Island of Krakatoa disappeared, with the exception of a bank of pumice and one small isolated rock, about 10 yards square, which was left standing above the ocean with deep water all round it. This rock consists of solid pitchstone, and probably represents a dyke or plug filling the throat of one of the volcanic cones that formerly occupied the old crater. At the same time a large portion of the northern part of the basaltic cone of Rakata was destroyed and a nearly vertical cliff formed, giving rise to a magnificent section which afforded a perfect insight into the internal structure of the volcano. (*See* Plate II., Fig. 2.) The depth of the great crateral hollow which was produced, where the northern part of Krakatoa formerly rose to heights of from 300 to 1,400 feet above the sea level, in some places exceeds 1,000 feet below that same level. (*See* Fig. 10, p. 23.)

In attempting to judge of the effects produced around the flanks of the great crater of Krakatoa, we have the two new and very detailed charts prepared by the Royal Dutch surveying vessel *Hydrograaf*, under Commandant C. VAN DOORN. The first of these was the result of a careful survey made immediately after the

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* Corresponding to the wave mentioned on p. 69 as 9 h. 58 m. Krakatoa time = 2 h. 56 m. G.M.T.

eruption, and was published on October the 26th, 1883, while the second appeared somewhat later, after the new Islands of Steers and Calmeyer had been reduced to sandbanks. These are reproduced as Plates XXXII. and XXXIII. following Part III.; but it is a very unfortunate circumstance that the old charts of the Strait of Sunda are far from accurate, and thus considerable difficulty arises when we attempt to make an exact estimate of the changes produced by the eruption. (*See* Fig. 11, p. 24.)

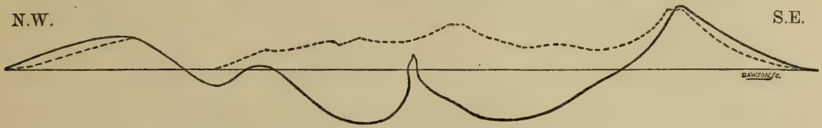

FIG. 10.—*Outline of the crater of Krakatoa as it is at the present time. The dotted line indicates the portions blown away in the paroxysmal outburst of August,* 1883, *and the changes in form of the flanks of the mountain by the fall of ejected materials upon them.*

Certain it is that the portion of the Island of Krakatoa which disappeared during the eruption was equal to about two-thirds of the original area, the part that remained consisting only of the southern moiety of the volcanic cone of Rakata. Of this fragment the southern outline, according to the new charts, differs considerably from that of the southern shore of the original island, and its height, if the old charts can be depended upon, was increased from 2,623* to 2,750 feet. But the top and sides of this fragment of the cone of Rakata are so covered by masses of ejected materials that the alteration in its form and height are, it appears to me, sufficiently accounted for without requiring us to call in any theory of general upheaval of the mass.

Of the other islands of the group, Poolsche Hoedje (Polish Hat) has entirely disappeared; Lang Island has been increased by an addition to its northern extremity, and its height above the sea seems to have been augmented, the whole of the vegetation that formerly covered it being deeply buried by ejected matters; and lastly, Verlaten Island has, by accretions on the side farthest away from the central crater, been enlarged to more than three times its former area, while a considerable addition has been made to its height.

In judging of the alterations in the form of the sea-bottom around the Krakatoa group, we have to rely upon the few and not very accurate soundings in the old chart of the Strait. From a comparison of these with the depths given in the new chart, we can scarcely doubt that over a circle with a radius of 10 or 12 miles from the centre of the Krakatoa volcano, the sea-bottom outside the great crater has been raised by an amount which varies from 10 to 60 feet. Mr. VERBEEK concluded however, that along a line 8 or 9 miles in length, and extending westward from the great crater, an *increase* of depth has taken place, and this is not improbably due to the opening of a fissure on the flanks of the submerged cone.

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* According to VERBEEK, the height previous to the eruption was 2,697 feet. After the eruption he says the height was 2,730 feet, but was reduced by June, 1886, to 2,677 feet.

In the so-called New or Sebesi Channel, between Krakatoa and Sebesi Islands, the original depth of water was much less than on the other sides of the Krakatoa group, seldom, indeed, exceeding 20 fathoms; and several rocks in this channel rose above the sea-level. After the eruption it was found that this channel was completely blocked by banks composed of volcanic materials, and two portions of these banks rose above the sea as islands, which received the name of Steers Island and

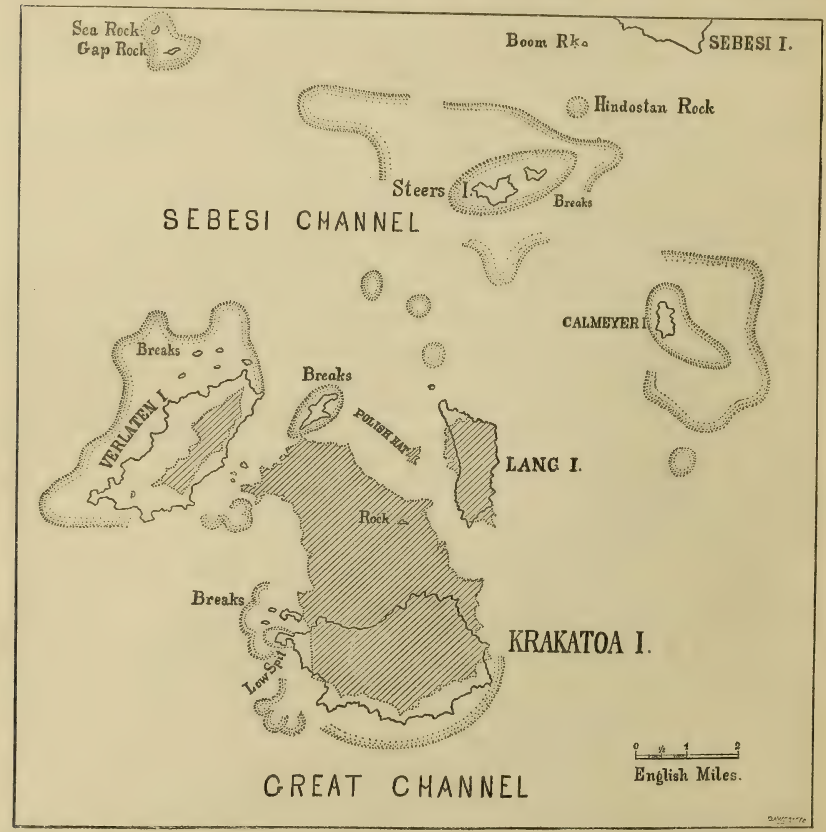

FIG. 11.—*Map of Krakatoa and the surrounding islands, from the Chart prepared immediately after the Eruption. Later charts show the islands of Steers and Calmeyer reduced to sandbanks. The shaded areas show the form of the islands according to the old chart. Much of the discrepancy between the southern limit of Krakatoa in the two maps is due to the imperfection of the old survey. Dotted lines show sand-banks and lines of breakers.*

Calmeyer Island. By the action of the waves, however, these islands were, in the course of a few months, completely washed away, and their materials distributed over the sea bottom.

The changes which took place in the forms of the islands and in the depth of the sea around them, have been supposed by some to indicate a general elevation of the islands of the Krakatoa group, accompanied by a great subsidence of the central or crateral area. A careful study of these changes in the light of what is known to have taken place at other volcanic centres leads me to adopt a wholly different conclusion.

The action going on within a volcanic vent during eruption is in all essential features identical with that which takes place in the throat of a geyser. In both cases we have a mass of heated liquid, in the midst of which large quantities of gaseous materials are being disengaged so as to escape into the atmosphere as the pressure is relieved, and these escaping gases carry up with them portions of the liquid in which they have been confined. Now just as the throwing of sods and earth into the tube of a geyser, by causing a check in the escape of steam and water and thereby leading to an augmentation of the tension of the elastic fluids below, gives rise to a more than usually violent explosion, so the interruption to the regular ejections going on at Krakatoa, consequent on the chilling of the surface of the lava in the vent by inrushes of sea-water, caused *a check and then a rally* of the pent-up force of gases seeking to escape from the molten mass. The serious catastrophic outbursts that produced such startling effects both in the air and in the ocean appear to me to have been the direct consequences of this "check and rally" of the subterranean forces.

In these last terrible outbursts, in which the volcano rapidly expended its remaining force, we are evidently dealing with the breaking up and ejection of solid lava constituting the framework of the volcano, and not with the simple dissipation of the lava-froth (pumice) as during all the earlier stages of the eruption. That the materials were not carried far from the centre of ejection is shown by the fact that no falls of coarse materials are recorded from any of the vessels that were within or near the Strait at the time, but the bulk of the solid fragments thrown out during these great explosions must have fallen back into the sea, upon and immediately around the flanks of the volcano itself. This is proved by the alteration in the forms of the islands of the Krakatoa group, and by the change in the height of the floor of the surrounding ocean. By these grand explosive outbursts the old crater was completely eviscerated, and a cavity formed, more than 1,000 feet in depth, while the solid materials thrown out from the crater were spread over the flanks of the volcano, causing the alterations in their form which have been noticed.*

It was the rush of the great sea-waves over the land, caused by the violent

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* It is probable that lateral eruptions contributed to the alterations produced by the ejection of materials from the central crater.

evisceration of the crater of Krakatoa aided by the impact upon the water of the Strait of the enormous masses of falling material, that caused the great destruction of life and property in the Strait of Sunda. By the inrush of these waves on to the land, all vessels near the shore were stranded, the towns and villages along the coast devastated, two of the lighthouses swept away, and the lives of 36,380 of the inhabitants, among whom were 37 Europeans, sacrificed. The first waves reached both the Javan and the Sumatran coasts between 6 and 7 on the evening of August the 26th, and these probably mark the time of the first influx of water into the igneous focus. A succession of small oscillations of the sea continued all night, but the waves that followed the four great explosions of 5.30, 6.44, 10.2, and 10.52 in the morning of August the 27th, were undoubtedly the highest and most destructive of all. The question of the nature and height of these waves, and the phenomena which accompanied them, are discussed in a subsequent part of this report. The areas submerged by these great waves is shown on the Chart, Fig. 9, p. 17.

Early on the morning of August the 27th, another phenomenon began to manifest itself. The vast quantity of watery vapour thrown into the atmosphere during the afternoon of the 26th and the night of the 26th and 27th of August, had reached an excessive height. This height has been estimated by Mr. JOLY at 17 and possibly even 23 miles, and by M. FLAMMARION at 12½ miles. This mass of vapour and dust, as so graphically described by Captain WOOLDRIDGE, of the *Sir R. Sale*, on reaching the limit of its elevation spread itself out laterally, giving rise to the "pine-tree" appearance so familiar to the Italians, who are in the habit of watching the paroxysmal outbursts of Vesuvius. All night long this great cloud spread itself laterally, the particles of dust slowly descending through the atmosphere. Between 10 and 11 a.m. the three vessels then at the eastern entrance of the Strait encountered the fall of mingled dust and water, which soon darkened the air and covered their decks and sails with a thick coating of mud. Some of the pieces of pumice falling on the *Sir R. Sale* were said to have been of the size of a pumpkin.

Between 10 and 10.30 a.m. the same state of things is reported in Lampong Bay, the *G. G. Loudon* being compelled at the latter hour to come to anchor on account of the darkness.

At Batavia, situated about 100 English miles from Krakatoa, the sky was clear at 7 a.m., but began to darken between that hour and 10 a.m.; at 10.15 the sky became lurid and yellowish, and, lamps began to be required in the houses; about 10.30 the first falls from the overhanging clouds took place in the form of fine watery particles, and this was succeeded by a few grains of dust; at 11 a.m. this increased to a regular dust-rain, becoming heavier till 11.20, when complete darkness fell on the city. This heavy dust-rain continued till 1, and afterwards less heavily till 3 p.m. The dust fell in small rounded accretions, containing about 10 per cent. of water. A similar phenomenon is recorded as having been observed during the recent eruptions of Tarawera in New Zealand.

At Buitenzorg, a little farther from the volcano, similar phenomena were recorded but were of shorter duration. The dust-fall commenced at 11, but darkness did not begin till noon, and it passed away as the dust-fall ceased at 2 p.m. The darkness, however, extended in the country eastward as far as Tjandjer, about 130 English miles, and Bandong, nearly 150 miles from the volcano.

The air-waves produced by the great explosions appear to have been of three kinds. Those which were of sufficient rapidity of alternation to give rise to sounds, are recorded as being heard as far away as Rodriguez and Diego Garcia, which are respectively 3,080 and 2,375 English miles distant from the volcano. Other waves of larger dimensions caused the bursting in of windows, and even the cracking of walls 100 miles away at Batavia and Buitenzorg. Lamps were thrown down, gas-jets extinguished, and a gasometer, under the influence of one of these great waves, leaped out of its well, causing the gas to escape. Even at much greater distances cracks were produced in walls, and all accounts agree in ascribing the result to air-vibrations and not to earthquakes.

The air-vibrations of still greater wave-length which travelled several times round the globe, as was first shown by General STRACHEY and Mr. SCOTT, are fully discussed in another part of this report, in which also details are given respecting the air-waves producing sound. (See Part II., p. 58.)

Eruptive action appeared to continue in the neighbourhood of Krakatoa during the whole of Monday, the 27th, though the darkness which prevailed over the Strait of Sunda prevented the exact nature of the operations going on there from being determined. Three vessels, the *Charles Bal*, the *Sir R. Sale*, and the *Norham Castle*, were all day beating about in the darkness at the eastern entrance of the Strait, the pumice-dust falling upon them in such quantities as to employ the crews for hours in shovelling it from the decks and in beating it from the sails and rigging. On board the *G. G. Loudon*, anchored in Lampong Bay, it is recorded that, after the rain of pumice-stone in the early morning, only dust and water fell in the form of mud, which accumulated on the deck at the rate of 6 inches in 10 minutes. Frequent explosions and vivid lightning in the neighbourhood of Krakatoa are recorded. After the great outbursts of the early morning of the 27th, however, it appears that there was a lull for a time, as at Buitenzorg no explosions were heard during the afternoon till 7 p.m. At this latter hour the explosions, as heard from Buitenzorg, recommenced, increasing in violence till 10 or 11 p.m., when they again declined, and finally ceased to be heard at 2.30 a.m. on Tuesday, the 28th of August.

On Wednesday, the 29th of August, the *G. G. Loudon* forced her way through the pumice-laden seas passing from the Bay of Lampong through the Strait of Lagoendie, and then sailed round the west, south, and east sides of Krakatoa, and thence on to Anjer, which place was reached at 4 p.m. They found that the whole of the northern part of the island of Krakatoa had disappeared, and that no smoke was at that time issuing from it. It was seen, however, that between Krakatoa and Sebesi "a reef had formed, and that various craters planted on that reef were sending columns of smoke on high."

On Wednesday, 29th, and Thursday, 30th, the *Sir R. Sale* and *Norham Castle* were working through the Strait from the east, and on the latter day were within ten miles of Krakatoa. Neither of the captains reports any kind of activity at Krakatoa, nor did either perceive the changes which had taken place in the island.

The steamer *Anerley* passed through Sunda Strait from the east on Tuesday the 28th; she kept close to the Java shore, and reports no eruptions as taking place at Krakatoa. The peak of Krakatoa was seen to be in its usual position, and no change was noticed in its form, or in that of other parts of the island.

Neither the captain of the *Berbice*, nor of the *Wm. H. Besse*, which passed through the Strait from the west and east respectively on August the 29th and 30th, reports any kind of action as being heard on those days in the direction of Krakatoa.

Those on board the *Prins Hendrik*, which entered the Sunda Strait on September the 3rd, noticed that from the part which remained of Krakatoa, from Lang and Verlaten Islands, from Steers and Calmeyer Islands, smoke continually arose, and now and then a flame was seen at night.

Commander Doorn of the *Hydrograaf* has suggested, from his inspection of the locality at a later date, that the steam proceeding from the hot pumice had been mistaken for eruptive outbursts, but there are some grounds for believing that lateral eruptions did take place on the flanks of Krakatoa after the outburst from the central crater had entirely ceased.

The soundings after the eruption indicate, as already pointed out, that a great depression or fissure had been formed in the sea-bottom, extending eastward of Krakatoa for a distance of about 7 or 8 miles, and extending nearly in the direction of the great line of volcanic activity which traverses Java and Sumatra. The formation of the islands of Steers and Calmeyer appears to be most naturally accounted for if we imagine that two or more parasitical volcanic cones had grown up on the northern flank of the Krakatoa volcano and had increased in size till they rose above the sea-level. In this state they appear to have been seen by those on board the *G. G. Loudon* on August the 28th; and in a later stage of degradation by those on board the *Prins Hendrik*, on the 3rd of September. These cones of loose pumice on rising above the sea-level were soon attacked by the waves, and as in the analogous well-known cases of Graham's Island and Sabrina, were gradually reduced first to sand-banks and then to shoals.*

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* The excessive quantity of material which must have been deposited in the channel between Krakatoa and Sebesi, to cause the formation of the two new islands and the surrounding shoals, has given rise to the suggestion that large portions of the volcano were actually hurled bodily into the air, and fell into the channel in question. But it is not necessary to adopt so improbable an hypothesis as this, when we remark the frequency of lateral eruptions upon volcanoes, and that we have in this case some direct evidence that small parasitical cones did actually exist at this point immediately after the great outburst.

There is considerable doubt as to whether several small eruptions did not occur in and about Krakatoa after the great outburst had died out on the 28th or 29th of August. The investigations by Mr. VERBEEK, however, have established the fact that a not inconsiderable explosion, accompanied by a rumbling sound, the ejection of large quantities of black mud, and a heavy sea-wave certainly took place at 9.30 p.m. on the 10th of October. The materials thrown out in this last exhibition of activity were afterwards clearly seen covering the slopes of the peak of Krakatoa, and the Island of Calmeyer, and the outburst must have been a by no means insignificant one.

Judged of by the quantity of materials ejected, or by the area and duration of the darkness caused by the volcanic dust, the eruption of Krakatoa must have been on a much smaller scale than several other outbursts which have occurred in historic times. The great eruptions of Papandayang in Java, in 1772, of Skaptar Jökull (Varmárdalr) in Iceland, in 1783, and of Tomboro in Sumbawa, in 1815, were all accompanied by the extrusion of much larger quantities of material than that thrown out of Krakatoa in 1883. The special feature of this last outburst of the volcanic forces was the *excessively violent though short paroxysms* with which it terminated. In the terrible character of the sudden explosions which gave rise to such vast sea and air-waves on the morning of the 27th of August, the eruption of Krakatoa appears to have no parallel among the records of volcanic activity. The peculiarity of the phenomena displayed during this eruption is, I believe, to be accounted for by the situation of the volcano, and its liability to great inrushes of the waters of the sea, as the evisceration of the crater opened a way to the volcanic focus. The manner in which these influxes of cold water would first moderate the volcanic action, and as a consequence give rise in the end to tremendous and exhaustive explosions of abnormal violence, I have already endeavoured to explain.

II. THE MATERIALS EJECTED FROM KRAKATOA.

As some very remarkable atmospheric phenomena appear to have followed the great outburst of Krakatoa, and these have been thought by many authors to have owed their origin, either directly or indirectly, to materials thrown into the higher strata of the gaseous envelope of our globe by these prodigious explosions, it may be well to inquire as to the exact nature and state of division of the substances which are known to have been ejected from the volcano.

Great facilities are afforded to us for studying the rocks of which Krakatoa was built up, by the magnificent sections produced during the great final outbursts. A fine volcanic cone, between 2,000 and 3,000 feet in height, had nearly half of its mass blown away, and the almost perpendicular precipices which were thus formed exhibit a wonderful succession of lavas and tuffs, the whole bound together by a network of vertical and oblique dykes. Never, perhaps, have geologists had so splendid an opportunity of studying the internal architecture of a compound volcanic cone, as that which has been afforded to them in the splendid ruin of Rakata. (*See* Plate II., Fig. 2.) The remaining slopes of the cone of Rakata are thickly buried under masses of pumice and other ejected materials, in which streams have cut deep radiating ravines. (*See* Plate II., Fig. 1.)

Underneath this ruin of the cone of Rakata, the older rock-masses of the island are seen making their appearance. I am much indebted to M. RENÉ BRÉON, who visited the district a few months after the great eruption, for carefully selected specimens of all the different types of rock exhibited in the interior of Krakatoa.

The Lavas.

The great bulk of the old crater-ring of Krakatoa is made up of massive outflows of an enstatite-dacite, which was found, on analysis, to contain 69·74 per cent. of silica. While the minerals contained in this rock are, on the whole, similar to those of the enstatite-andesites so abundant in Java and Sumatra—namely, plagioclase felspar, ferriferous enstatite (hypersthene), augite, and magnetite—the proportion of the base to the included crystals appears to be very different in the two cases. The Krakatoa-rock contains at least 90 per cent. of base to 10 per cent. of crystals; and as this base is of a much more acid character than the crystals themselves, the Krakatoa rock has a silica percentage of 70, while the ordinary andesites of Java and Sumatra, which contain a very much smaller proportion of base to included crystals, contain only between 52 and 61 parts in 100 of silica. (*See* Plate III., Fig. 1.) We have here a very instructive illustration of the necessity of taking into account, not only the *species* of minerals contained in a rock, but the *proportions* in which they are present. A rock of very similar character to that so abundant at Krakatoa was described as occurring at Java's First Point and Princes Island by MM. VERBEEK and FENNEMA, and such highly acid varieties were, perhaps, characteristic of the ejections from the transverse fissures of the Strait of Sunda.

These older lavas are sometimes compact and at other times vesicular. In the latter case the cavities are remarkable for the fine crystals of tridymite, sometimes accompanied by hornblende and quartz, which they contain; these have been described and figured by Professor VOM RATH.* The crystals of tridymite appear to me to be of secondary origin, and to have been developed in the cavities of the rock by the passage of acid vapours.

The base of these old lavas, which is of a reddish-brown colour, is seen under the

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* 'Verhandlungen des naturh. Vereins de preuss. Rheinl. u. Westf.,' 1884, pp. 326–333. Taf. vi., fig. 18.

microscope to consist of glass crowded with microlites of felspar, augite, enstatite and magnetite, the latter often converted into flecks of hydrous-brown oxide which give the rock its peculiar tint. What are believed to be microlites of tridymite have also been described as occurring in the base of the rock. (*See* Plate III., Fig. 2.) The porphyritic crystals of felspar, enstatite, augite, and magnetite are similar to those found in the later rocks of Krakatoa, which will be noticed more fully hereafter.

In the walls of the old crater-ring of Krakatoa (as at Polish Hat and the south end of Lang Island), and among the materials that have been ejected within it, there are found also some very interesting porphyritic pitchstones of a velvety-black colour. These rocks are proved by analysis to have precisely the same chemical composition as the associated stony lavas. The included porphyritic crystals are also precisely the same. These rocks, except for the proportion of the glassy base to the crystals, bear a very striking resemblance to the "porphyritic pitchstones" of the Cheviot Hills which have been made so well known to petrologists by the descriptions of Mr. TEALL and Dr. PETERSSEN. The glassy base of these rocks is of a rich brown colour by transmitted light, and is crowded with microlites, a beautiful fluidal structure being often exhibited in it. (*See* Plate III., Fig. 4.) In certain parts of the Cheviot Hills I have found a stony lava very similar in appearance to that forming the bulk of the crater-ring of Krakatoa, passing at the surfaces of the lava-streams into the well-known velvety-black porphyritic pitchstone of the district, and it is probable that similar relations exist between the analogous rocks at Krakatoa. With these lavas only very insignificant beds of tuff have been found associated.

The next lavas ejected at Krakatoa present a very striking difference from those just described. They are seen in the great lateral peak of Rakata, which was built up by a succession of eruptions from a vent opened on the edge of the great crater. The unconformity of these basaltic lavas, and of the tuffs of the same composition alternating with them, to the older dacites is well seen in the great natural section produced by the eruption of 1883. (*See* Plate II., Fig. 2.) These basalts do not offer much subject for remark; some appear to contain much greater proportions of olivine than others, and there are variations in the degree of crystallization of the materials. A specimen which was analysed gave a percentage of 48·81 of silica.

With the eruption of the materials which covered the lower and northern part of Krakatoa we find a return to the earlier types of lavas. They all consist of enstatite-dacites with about 70 per cent. of silica. Indeed the ultimate chemical composition, and the nature of the porphyritic crystals embedded in these youngest lavas are so similar to those of the earliest period, that the re-fusion and outwelling of some of the lower portions of the mass are very strongly suggested by their study.

Concerning the materials thrown out during the last eruption of Krakatoa, we have fortunately a large number of valuable observations made both by chemists and by mineralogists ; and the study of these materials is, I believe, calculated to cast much new light upon certain vulcanological problems.

Mr. VERBEEK computes that of the materials thrown out between May the 20th and the period when the whole solid framework of the interior of the volcano was blown up, at least 95 per cent. consisted of pumice and dust, and not more than 5 per cent. was made up of compact lava and of fragments torn from the side of the vent. As the pumice and dust were all formed, as we shall see, from the compact lava, it will be convenient to describe this at the outset.

The compact lava of 1883 presents itself under two different forms, the distinctions between which are worthy of the most careful study. These two rocks may be characterised as porphyritic pitchstone, and porphyritic obsidian. In both these the crystalline elements are the same, and constitute only about 10 per cent. of the whole bulk of the rock. Of these crystalline elements felspar constitutes about two-thirds, crystals of pyroxene about one-third as much as the felspar, and magnetite about half the bulk of the pyroxenes. The crystals do not appear to be scattered by any means uniformly through these rocks, but little groups, each containing a number of crystals of felspar, pyroxene, and magnetite are found at intervals in the ground-mass. The pyroxenes include the two different forms, a rhombic pyroxene or enstatite, and a monoclinic form or augite; the former appearing to be about twice as abundant as the latter. In addition to the essential minerals of the rock, apatite, pyrite, and pyrrhotine (magnetic pyrites) were found to occur in small quantities as accidental or accessory constituents. Perhaps the most striking feature of these rocks is the large proportion borne by the base to the crystalline elements diffused through it.

The average composition of this rock is probably well represented by an analysis made by Professor C. WINKLER, of Freiberg, in Saxony, of a mass of the Krakatoa pumice, collected by Mr. VERBEEK upon the island on October the 16th, 1883. Its specific gravity was found to be 2·329. Omitting the moisture and substances soluble in water, the composition was found to be as follows :—

Silica	68·99
Titanic acid	0·82
Alumina	16·07
Ferric oxide	2·63
Ferrous oxide	1·10
Manganous oxide	0·28
Lime	3·16
Magnesia	1·08
Potash	1·83
Soda	4·04
	100·00

Mr. J. W. Retgers, of Buitenzorg, taking the dust which fell at that place, which was very carefully collected so as to avoid accidental admixtures, and employing the most delicate and refined methods for separating the particles of glass from those of crystalline minerals, and the several varieties of the latter from one another, has been able to isolate and analyse the several constituents of these rocks. His results are given in the following table. The optical and other characters of the minerals of these rocks, as exhibited in the dust derived from them, also have been studied by Richard,[*] Renard,[†] Sauer,[‡] H. H. Reusch,[§] Oebekke,[‖] Von Lasaulx,[¶] Carvill Lewis,[**] Joly,[††] Waller,[‡‡] R. Bréon,[§§] and myself,[‖‖] as well as by MM. Verbeek, Retgers, and Winkler.[¶¶]

	Glass. (All materials having a specific gravity less than 2·6.)	Felspar. Average of all kinds present.	Enstatite. Highly ferriferous. (Amblystegite).	Augite.	Magnetite. (With Ilmenite.)
Silica	68·12	58·29	52·3	48·6	—
Titanic Acid	0·18	—	—	—	6·7
Alumina	15·81	27·19	6·1	8·2	—
Ferric Oxide	—	—	—	—	56·0
Ferrous Oxide	5·01	—	27·7	14·0	37·3
Manganous Oxide	—	—	trace.	—	—
Lime	2·78	8·27	2·2	18·9	—
Magnesia	1·18	—	13·6	11·6	—
Potash	1·06	1·22	—	—	—
Soda	5·09	5·82	—	—	—
	99·23	100·79	101·9	101·3	100·0

With respect to the felspars of those rocks, MM. Verbeek and Retgers have arrived at the interesting conclusion that all the varieties of plagioclase are present together in the same mass. They conclude that 85 per cent. of the felspar-crystals,

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[*] 'Comptes Rendus.' Séance du 19 Novembre, 1883.

[†] 'Bull. de l'Acad. Royale de Belgique,' 3ième Ser., t. vi., 1883.

[‡] 'Berichte der Naturf. Gesellsch. zu Leipzig,' 1883, p. 87.

[§] 'Neues Jahrb. für Min.,' &c., 1884, I. Bd., p. 78.

[‖] 'Neues Jahrb. für Min.,' &c., 1884, II. Bd., p. 32.

[¶] 'Sitzg. d. niederrh. Ges. in Bonn' (Sitzg. vom 3 December, 1883).

[**] 'Proc. Acad. Nat. Sc.,' Philadelphia, 1884, p. 185.

[††] 'Royal Dublin Society,' N.S., vol. 4, p. 291.

[‡‡] 'Birm. Nat. Hist. and Microscop. Soc., Rep. and Trans. for 1883,' p. vi. (March 4th, 1884).

[§§] 'La Nature,' 13me Année (1885), p. 373.

[‖‖] 'Nature,' vol. xxix., p. 595.

[¶¶] 'Krakatau,' pp. 185–324.

however, are lime-soda felspars, intermediate between the very acid and the very basic types, and would, according to the ordinary mineralogical nomenclature, be ranked as labradorite, andesine, or oligoclase. Smaller quantities of anorthite, albite, and potash-plagioclase (anorthoclase of Rosenbusch), also are found in the rock. These results are of very great interest to petrographers. Many rocks have been shown to contain felspars belonging to more than one species; the felspars of the first and second consolidation in a rock, indeed, usually differ considerably in composition. In the same crystal, too, we may find a number of successively formed zones, having different chemical composition and optical properties; and crystals of plagioclase may be found actually surrounded by a zone of orthoclase. Never, however, as far as I am aware, has so great a diversity of felspar-crystals been recorded in the same rock as in that of Krakatoa. It must be remembered, however, that the conclusion of MM. VERBEEK and RETGERS is founded, not on the study of a rock itself, but on the dust produced by the comminution of great masses of rock in which considerable diversity of mineralogical constituents may have existed. The felspar-crystals of the Krakatoa-rocks are usually remarkable for the striking zoned structure exhibited by the individual crystals.

The enstatite of these rocks is of a deep tint and highly pleochroic. According to the analysis of M. RETGERS, indeed it must be regarded as containing a higher percentage of iron than the ordinary hypersthenes; and if we follow the nomenclature which I have suggested for the varieties of enstatite, it should be classed as an amblystegite.

The augite, which is aluminous and contains a high percentage of lime, is of a pale olive-green tint and exhibits only a very feeble pleochroism. Examples of intergrowth of the monoclinic augite and the rhombic enstatite, the corresponding axes of the two crystals being in parallel positions, are not unfrequent.

In addition to magnetite, in these rocks there have been found ilmenite, pyrite, pyrrhotine, apatite, and some secondary products.

There is often a marked contrast between the porphyritic felspar-crystals embedded in the two types of glassy dacite rocks. In the obsidians, the crystals of felspar have sometimes perfectly sharp outlines; they contain glass-cavities, often with the rectangular outlines of negative crystals, containing gas bubbles. The brown glass filling these cavities is much darker in colour than the glass of the ground-mass, though traces of a similar brown glass are often seen adhering to the sides of the knots of crystals (*See* Plate III., Fig. 5). The crystals are not unfrequently broken, and are sometimes bent; in the latter case the development of the lamellar twinning in them is seen to have been determined by the strain to which they had been subjected.

In the pitchstones, the felspar-crystals more frequently have their angles and edges rounded, and through the whole of their interior a great amount of corrosion has taken place, so that the crystals now appear as mere skeletons, the glass which has eaten into the crystals being much greater in bulk than the crystalline material that remains. In eating into the substance of the crystals the corrosive material has evidently taken advantage of planes of chemical weakness in the crystals; but it is remarkable that in many cases there is an outer zone which remains almost intact. (*See* Plate III., Fig. 3.*)

Let us now turn our attention from the crystals scattered through these rocks, to the base, or ground-mass, in which they are embedded.

The porphyritic pitchstone of the 1883 eruption appears to be almost absolutely identical in its characters with the older material already referred to as forming Polish Hat Island, and also occurring at the south end of Lang Island and other points in the old crater-ring. (*See* p. 31.) It is black and perfectly opaque, except in very thin sections, and has a *resinous* lustre. Under the microscope the base of the pitchstones is seen to be formed of a felted mass of microlites of felspar and pyroxene, with grains of magnetite, and the whole mass has its interstices filled with a yellowish or brown glass. The base often exhibits a banded or fluidal structure. (*See* Plate III., Fig. 4.)

The porphyritic obsidian on the other hand has a strikingly *vitreous* lustre. By reflected light it is of a very dark brown, nearly black, colour; by transmitted light, of a rich yellowish-brown tint; while in thin sections it is almost colourless. In the midst of this glass may be seen a very few scattered microlites of felspar and pyroxene, these bearing but a very small proportion indeed to the glass in which they are enclosed, and in this respect the obsidians offer a very striking contrast to the pitchstones above described. (*See* Plate III., Fig. 6.)

Occasionally, however, rocks are found which are intermediate in the characters of their base between the obsidians and the pitchstones.

The most striking differences between these two rocks are seen, however, when they are subjected to a high temperature. Before a gas-flame, urged by a foot-blast, the pitchstone is found to decrepitate, but to undergo fusion only with the greatest difficulty. The obsidian, on the other hand, is fused with comparative ease, and during fusion, bubbles and swells up into cauliflower-like masses, which will float on water. These white cauliflower-shaped masses have exactly the colour and appearance of the pumice ejected from Krakatoa, and on making thin sections of them and comparing them with sections of the Krakatoa-pumice, their structure is found to be almost absolutely identical. (*See* Plate IV., Fig. 4.) The loss suffered by the pitchstones on ignition is almost nil, while the obsidians lose from 1, to 5 or 6 per cent. of their weight.

In the case of the curious marekanite of Siberia, and of a mica-dacite glass from Fifeshire, I have already pointed out the tendency of glasses containing large quantities of water to undergo fusion at comparatively low temperatures, and while doing so to part with their volatile ingredients, becoming thereby converted into pumice.†

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* The Plates II., III., and IV. will be found at the end of this Part, *i.e.*, after p. 56.

† 'Quart. Jour. Geo. Soc.,' vol. xlii. (1886), p. 429; 'Geol. Mag.,' Dec. iii., vol. iii. (1886), p. 243.

The Pumice.

The pumice which was thrown out in such enormous quantities during the latest eruption of Krakatoa, was evidently formed by the disengagement of volatile matters, throughout the whole substance of this obsidian. The formation of this pumice can indeed be exactly imitated if we take a strong solution of bicarbonate of soda, rendered slightly viscous by the addition of gum, and made nearly opaque by the addition of some brown colouring matter, and allow an acid to diffuse itself through the mass. The carbonic acid, as it becomes disengaged, will distend the whole mass to five or six times its original bulk, owing to the formation of gas bubbles in its midst, and we get a white mass of froth exactly resembling pumice. Nothing can be more certain than the fact that the volatile substances which, escaping in such quantities from the vent of Krakatoa, gave rise to the last eruption, were originally imprisoned *in every part of the glassy mass.* The whole of the pumiceous substance is penetrated with the finest vesicles produced by the disengagement of gas. Those fragments of the lava which had cooled so far as to become consolidated before ejection, only require to be heated in order to give off their volatile ingredients; and in doing so the melting glass is converted into a true pumice. In what condition water and other volatile substances exist in these glassy rocks is still to some extent an unsolved problem. Such rocks may lose from 1 to 10 per cent. on ignition. It is certain, however, that the water or other substances do not exist in any cavities visible under the highest powers of the microscope, and it is probable that they are in actual combination with the glass or colloid body.

The presence of from 3 to 16 per cent. of water in opals or colloid silica, is probably a perfectly similar case. Colloid bodies appear to have this power of taking up and of retaining large quantities of water and other volatile substances. The difficulty of removing the last traces of water from precipitated colloid silica is very well known.

The pumice of Krakatoa is found presenting two different varieties. By far the rarest of these is a perfectly white material of very fibrous texture, closely resembling the well-known pumice of Lipari. In this variety porphyritic crystals do not appear to be present. I received a specimen of this variety from Mr. H. O. FORBES, to whom it was given by one of the party from Batavia that visited Krakatoa on May 27th, 1883; the mass, which was about 2½ inches in diameter, was among the fragments thrown out during the earliest stage of the eruption. (*See* Plate IV., Figs. 1 and 2.)

The great mass of the pumice thrown out during the eruption, however, presented a dirty greyish-white tint, the air-pores in it being very irregular in size, and sometimes large. Scattered all through the mass are little knots of crystals of felspar, pyroxene, and magnetite, distributed at somewhat wide intervals. When, as was usually the case, the pumice was rounded, either by the striking of fragments in the air or by their attrition while floating on the ocean, the little knots of crystals, on account of their superior hardness, stand out like warts on the surfaces of the masses. In addition to these knots of crystals there are sometimes found little fragments of black glass, and these, when examined in thin sections, are seen to be composed of the pitchstone already described, often containing the usual porphyritic crystals, which are in such cases remarkably corroded. (*See* Plate III., Fig. 3.)

The formation of this pumice by the escape of imprisoned volatile matters in the obsidian, while it was still in a viscous condition, is abundantly illustrated if we examine its structure microscopically; the glass is seen to be drawn out into plates and threads of all dimensions. (*See* Plate IV., Figs. 1, 2, 3.) In specimens of pumice which were collected on Krakatoa, and had not been immersed in the sea-water, the microscope often reveals delicate fibres of spun glass running from one side of a cavity to the other, and these are frequently of the smallest dimensions which can be recognised by the microscope. In this connection we may recall the ingenious experiments of Mr. C. V. Boys, who has managed to draw out threads of glass of ultra-microscopical dimensions; the existence of which could be proved, however, by their diffraction effects.* That similar ultra-microscopical threads were formed in the cavities of the Krakatoa-pumice we have every reason for believing.

In order to determine the amount of distension which the obsidian underwent in its conversion into pumice, rectangular blocks of the latter substance were cut and carefully measured and weighed. The fine-grained, very dense, white pumice was found to have nearly three and a half times the volume of the glass out of which it was formed; and the much more common dirty-grey pumice was found in average examples to have undergone a dilatation to five and a half times its original bulk, and this in spite of the fact that something like one-tenth of the original lava consisted of undilatable crystals, which remained to weight the mass. Owing to the existence of the heavy crystals diffused through it, and the fact that water enters it to some extent by the large open pores, the ordinary Krakatoa pumice was found to float with two-thirds of its bulk submerged and one-third above the water. Much of the pumice, in which the air-cells were exceptionally large, was far more bulky in proportion to its weight; and some of these pieces projected to enormous heights in the atmosphere, appear to have been swept great distances by air-currents before they finally fell into the sea.

The study of the pumice of Krakatoa shows that the greater part of the glass of which it is composed depolarises light to a greater or less extent. It is evident, therefore, that it is in a condition of intense strain, the result of the rapidity with which it cooled. To the same cause must probably be ascribed its extreme brittleness, for it can be easily crumbled between the fingers.

In addition to the analysis of the pumice of Krakatoa published by Professor C.

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* 'Phil. Mag.,' Series V., vol. xxiii. (1887), p. 489.

Winkler, of Freiberg, I add the following, which has been kindly furnished to me by Mr. T. H. Waller, of Birmingham :—

Silica	69 4
Alumina	15·9
Ferric oxide	1·2
Ferrous oxide	2·2
Lime	3·4
Magnesia	1·1
Soda	4·2
Potash	2·3
Loss on ignition	1·0
	100·7

The chloride of sodium and other soluble matter with which the pumice was impregnated from floating in sea water was removed by washing before this analysis was made.

As far as I have been able to determine, the pumice ejected from Krakatoa before and during the last violent stage of the eruption was identical in character. As this material was being thrown into the sea during nearly four months, it is impossible to determine at what date any particular specimen found in the ocean may have started on its journey, and consequently the hope of determining the direction and rate of the marine currents by which they were distributed must be abandoned. It may be added, that as the Krakatoa-pumice floats with so large a portion of its mass above the water, prevalent winds might have much influence in determining or modifying its movements.

Dr. C. Meldrum, F.R.S., of Mauritius, had special facilities for collecting observations on the subject of the distribution of this pumice, and his notes on the subject, which were presented to the British Association, were published in 1885. They are reproduced as an Appendix to this report, together with a Memorandum on the subject by Mr. Robert H. Scott, F.R.S. (pp. 47, 48).

The Volcanic Dust.

Let us now proceed to the study of the volcanic dust which was formed in such enormous quantities during the Krakatoa eruption.

That steam escaping from a mass of molten glass may carry off fine particles of the substance, often dragging it out into threads, appears highly probable. That such is actually the case I was able to prove by heating the little obsidian-balls known as "marekanite," when clouds of finely-divided particles were seen to be driven off from its mass. But the great bulk of the volcanic dust of Krakatoa was undoubtedly formed by the striking together of fragments of pumice as they were violently ejected from the crater and fell back again into it. The noise made by this hurtling of fragments in the air was remarked upon by several observers, and as I have myself noticed at Stromboli, is often more striking than the sound of the explosions. The action of this "dust-making" mill, as an active volcano undoubtedly is, was well illustrated during the Vesuvian eruption of 1822. Mr. SCROPE, who was an eye-witness of that eruption, describes how day after day as the eruption proceeded the dust-particles became finer and finer, till at last they were able to penetrate the finest cracks, finding their way into and filling all locked boxes, drawers, and similar receptacles.

The extreme brittleness of the glass of the pumice, which I have before remarked upon, as the result of its sudden cooling, would facilitate its pulverization; and as it was reduced to powder it would remain longer in the atmosphere, and be swept farther away from the central ascending steam-column. The large fragments of pumice would be re-ejected again and again as they fell back into the crater, each time being reduced in bulk and weight. All the ejected blocks of pumice bore obvious marks in their rounded form of this attrition in the air, and the work of rounding and reduction in bulk went on after they reached the ocean, and were swept by currents and driven by winds.

If a piece of the Krakatoa pumice be pounded in a mortar, and the dust so formed be mounted and examined microscopically, it will be found to agree in the form of its particles and its general characters with the volcanic dust which fell at so many points around the volcano. (*See* Plate IV., Fig. 6.)

Through the kindness of many correspondents I have had the opportunity of studying a very large number of samples of the Krakatoa-dust, collected from many points, ranging from 40 to 1,100 English miles away from the volcano.

Even to the naked eye, striking differences are manifest among these various specimens. Those collected nearest to the volcano obviously consist of coarser particles, and they are of a somewhat darker tint owing to the greater abundance in them of fragments of crystals, especially those of magnetite and other dark-coloured minerals. Those dusts which were collected at the greatest distance from the volcano were excessively fine and almost perfectly white in colour. Professor WINKLER describes the dusts which fell at Krakatoa as having a darker tint and a higher specific gravity than those which fell at Buitenzorg.

Under the microscope the differences between the dusts collected at different points come out in a very striking manner.

A considerable number of analyses of the Krakatoa dust have been made by different observers, and for the sake of comparison I have placed three of these side by side. I have in each case rejected the volatile matters and calculated the totals to 100.

Analyses of the Dust of Krakatoa which fell at different distances from Krakatoa.

	A.	B.	C.
	Dust which fell at Krakatoa.	Dust which fell at points within 100 miles from the Volcano.	Dust which fell nearly 900 miles from the Volcano.
	Collected by Captain Ferzenaar.	Buitenzorg.	*S. Barbarossa.*
	Prof. C. Winkler.	Prof. C Winkler.	A. Schwager.
Silica	61·36	66·77	68·99
Titanic Acid	1·12	0·67	0·39
Alumina	17·77	16·44	15·24
Ferric Oxide	4·39	3·41	0·28
Ferrous Oxide	1·71	1·37	3·72
Manganous Oxide	0·41	0·38	trace.
Lime	3·45	2·90	2·76
Magnesia	2·32	1·67	0·83
Potash	2·51	2·25	3·47
Soda	4·98	4·14	4·32

Let us now consider the causes which would affect the composition of the dust which fell at different points, and at varying distances from Krakatoa.

By the influence of the great upward currents of steam, an immense mass of comminuted particles of pumice would be carried to the height of many miles into the atmosphere. Nine-tenths of this material consisted of a glass having a specific gravity of less than 2·3, drawn out into fine threads and thin plates, often hollow and containing bubbles of air, and sometimes, in all probability, reduced to particles of ultra-microscopic dimensions. These particles of glass would tend to float by the adhesion between them and air, and, in the higher and rarer portions of the atmosphere, their suspension may not improbably have been aided by their mutual repulsion resulting from a highly electrified condition.

The crystalline particles in the mass would consist of fragments of felspar, with a specific gravity ranging from 2·54 to 2·75, of fragments of pyroxene with densities of 3·3 to 3·5, and of magnetite, with a density of 5·0. The crystals of felspar, hypersthene and augite were, in the original pumice, of much greater size than the magnetite. But the easy double cleavage in the felspars, and to a smaller extent in the pyroxenes, would facilitate the reduction of these minerals to finer particles than the magnetite.

As the particles travelled outwards from the centre, they would tend to fall, therefore, in the following order:—1. Magnetite (the heaviest and least friable material); 2. Pyroxenes (next in weight and only moderately cleavable); 3. Felspar (lighter and very cleavable); and 4, and last, the very light and friable glass.

At all points, therefore, the dust which fell would have a tendency to differ in composition from the pumice out of which it was formed. Near the volcano the abundance of the crystalline materials falling, and especially of the magnetite and pyroxenes, would render the dust darker in colour and more basic in composition; while farther away the glass- and felspar-particles which fell would have a smaller admixture of the more basic materials. A certain proportion of the glass, including the ultra-microscopical, the elongated, and the very thin particles, would float almost indefinitely, and would not find any place in the masses of dust collected around the volcano.

Besides this it must be recollected that there are always particles of both organic and inorganic dust floating in the atmosphere, and these would be carried down mingled with the volcanic materials. In every sample of Krakatoa-dust which I have examined, these ordinary constituents of the atmosphere could be detected.

Further than this, the steam issuing from the volcano was mingled with both hydrochloric and sulphurous acids, the latter taking up oxygen and passing into sulphuric acid. By these powerful acids the finely-divided particles of crystals and glass would be easily attacked, sulphates and chlorides of lime, magnesia, iron, and the alkalies being formed. All these substances were found in greater or less abundance in the specimens of dust from various localities.

Concerning the quantity of dust thrown into the air during the Krakatoa eruptions, we have no data for forming any trustworthy estimate. The continuance for more than three months of the work of trituration among the masses of pumice, of so particularly brittle a character as that ejected from Krakatoa, must have given rise to a large quantity of fine particles which would be gradually diffused in the higher regions of the atmosphere. The last violent outburst, however, was of but short duration, and the area over which the dust-cloud spread, and the time during which darkness prevailed, were small as compared with the area and duration of the dust-cloud during the Tomboro and some other great eruptions.

On the other hand, it may be remarked that there is reason for believing that the last paroxysmal discharges from Krakatoa were of altogether exceptional violence, and that water- and lava-dust may have been forcibly carried into those higher atmospheric strata which are characterised by extreme rarefaction and great electrical repulsion—strata into which, in ordinary circumstances, such particles have no chance of finding their way.

What was the percentage of ultra-microscopical particles which remained in the atmosphere after the larger ones had fallen it is impossible to determine, but it was not improbably very considerable. It is for physicists to determine whether such particles were capable of producing the wonderful optical phenomena which followed the eruption of Krakatoa, either acting by themselves, or performing the part of condensers of watery vapour, in the manner which Mr. AITKEN has shown such particles to be capable of doing.

A question which has often been asked is :—If the optical phenomena in question resulted from the presence of fine particles floating in the atmosphere, might not these be carried down by rain and detected after they had fallen? I am indebted to a very large number of correspondents, who, ever since the great eruption, have been sending to me specimens of dust, of materials scraped from freshly fallen snow, and the sediments found in rain-gauges. But although the study of these was very interesting in itself, yet as far as aiding to establish the presence of the Krakatoa-dust in the atmosphere went, the results have been altogether negative.

Nor is this result different from what might have been anticipated, as a little consideration will serve to show. The most characteristic substance in the Krakatoa dust is the rhombic pyroxene (enstatite). But this is one of the substances which, from its high specific gravity and its slight friability, would be among the first to fall. Moreover, this mineral occurs much more widely than was at one time supposed, being found very commonly in many of the andesites, which are the most widely diffused of all lavas, except perhaps the basalts.

None but those who have had occasion to study the matter for themselves can have any idea of the quantity of mineral particles which are everywhere floating about in the atmosphere ; but those of local origin of course usually largely predominate, and serve to mask the particles which have come from great distances. If the optical phenomena which followed the eruption of Krakatoa are rightly regarded as being due to dust in the atmosphere, they would probably result from the action of ultra-microscopical particles, for it is these, which, by scattering light, have the power of producing colour-effects. Such particles it is of course hopeless to attempt to seek for in the manner described.

GENERAL CONCLUSIONS.

The thoughtful consideration of some of the facts which have been detailed in the foregoing paragraphs is calculated, I believe, to afford an important insight into the nature of the forces which give rise to volcanic outbursts, and to the causes of the variation in character of these phenomena, in different places and at various times.

All the materials ejected from the *central* vent of Krakatoa have been wonderfully similar in their chemical and mineralogical constitution. At one period of the volcano's history, it is true, basaltic lavas and tuffs were thrown out from a *lateral* vent, and of these the parasitical cone of Rakata is built up ; but both before and since this episode in the history of Krakatoa, the materials ejected from the central crater have always belonged to the remarkable class of enstatite-dacite rocks. The composition of these rocks may be represented by the following general averages :—

Silica (with Titanic Acid) ..	70
Alumina	15
Oxides of Iron	4
Lime and Magnesia	5
Potash	2
Soda	4
Total	100

In this magma apparently, by a first consolidation, well-developed crystals, equal to about 10 per cent. of the whole mass, seem to have been separated, these crystals consisting of 6 per cent. of felspar, 2 per cent. of ferriferous enstatite and augite (the former mineral being twice as abundant as the latter), and 2 per cent. of magnetite. Making a calculation on the basis of the composition actually found by analysis for the whole rock, and the several minerals present, the base or ground-mass of these rocks would have the following composition :—

Silica (with Titanic Acid) ..	72·8
Alumina	14·7
Oxides of Iron..	1·8
Lime and Magnesia	4·4
Potash	2·2
Soda	4·1
Total	100·0

This magma exhibits a greater or less degree of devitrification in different cases, microlites of felspar, pyroxene, and magnetite belonging to a second period of consolidation, separating from it sometimes in small quantities, at other times to such an extent as to convert the glassy base into a stony one.

It is scarcely possible to doubt that the separation of the larger and porphyritic crystals from the magma, must have taken place under totally different conditions from those of the second consolidation; in all probability, when the mass existed at great depth and under intense pressure. And it is by no means certain that the proportion of glassy matrix to the included minerals has not been altered since the crystallization of the latter.

Now the startling fact which comes into prominence when the lavas of the earlier and later periods of eruptive activity at Krakatoa are studied in the field is that, in spite of this identity in chemical composition and of the included minerals, their mode of behaviour has been strikingly dissimilar.

During the earlier period, massive lava-streams flowed from the central vent, almost unaccompanied by any explosive action, and these lavas gradually accumulated to build up a bulky cone. In these massive lavas the slow cooling down of the molten rock permitted of the imperfect crystallization of the felspar, pyroxene, and magnetite from the base; where the cooling was somewhat rapid, magnetite and felspar were the chief minerals formed, as in the pitchstones; where less rapid, felspars and pyroxenes, as in the stony lavas.

But during the later period a lava having precisely the same chemical composition exhibited perfect liquidity. Occasional lava-streams composed of this material are found, as at Perboewatan, but the greater portion of it, on being relieved from pressure by coming into the outer atmosphere, at once became distended into pumice, through the escape of the volatile materials imprisoned in its midst.

Now, what is the cause of the difference of behaviour of the same chemical compound in these two cases? It might, at first sight, appear that the cause of this difference is to be sought in variations of temperature, and that the later lavas were more liquid because at a higher temperature, and more thoroughly fused than the earlier ones.

But if we examine the porphyritic crystals of the same minerals which have floated about in the magma in both cases, we shall find that all the evidence points to exactly the opposite conclusion, namely, that the pitchstone-rock was actually at the higher temperature, for the crystals of felspar in the obsidian-rock are often almost uncorroded, while in the pitchstone they have been attacked by the fluid in which they floated, and have indeed been to a great extent dissolved by it.

If we now try the actual fusibilities of the magmas in the two cases, we shall find the inference derived from the condition of the felspar-crystals to be strikingly confirmed. In the case of the pitchstone, portions of the substance held in the flame of a jet urged by a strong blast are hardly affected, while in the case of the obsidian the material under the same conditions rapidly becomes liquid.

But this production of liquidity in the obsidian is attended with the disengagement of a large quantity of volatile materials by which the rock rapidly passes into the condition of a pumice. It is, therefore, impossible to avoid connecting the presence of these volatile matters in the rock with the production of its liquidity.

I have in another place* pointed out that the leucite-basalts of similar composition ejected from Vesuvius at different periods exhibit just the same differences. When, as in the lavas of 1872, the quantity of steam and gas given off from them

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* See 'Geol. Mag.,' Dec. ii., vol. ii. (1875), p. 68; also 'Volcanoes,' p. 92.

was large, their liquidity was perfect; when, as in 1858, the quantity of volatile matter was small, the lavas exhibited the greatest viscosity.

That by admixture with varying quantities of water many salts have their fusion-points proportionately reduced has long been known. Indeed, the late Dr. GUTHRIE, F.R.S., by his interesting experiments upon nitre, was able to demonstrate that there is actual continuity between the two states of fluidity known by the names of *solution* and *fusion* respectively. For, as there is a perfectly gradual rise in the temperature at which liquidity is produced when more and more nitre is added to a definite quantity of water, it becomes impossible to decide when the proportion of the water becomes so small that we can no longer regard the case as one of "solution," and we must begin to call it "fusion."*

That the silicates, like other salts, have their fusion-points lowered by admixture with water, we have many proofs. Most of the felspars are minerals of difficult fusibility, while the zeolites, which are analogous compounds of the silicates of alumina and the silicates of potash, soda, and lime, with the addition of water, are remarkable for their easy fusibility and for the manner in which they swell up and lose their waters at a comparatively low temperature. And this is true, not only of definite hydrous silicates, like the zeolites; the colloids of indefinite chemical composition, such as tachylyte, hydrotachylyte, and palagonite, appear to have their fusion-points lowered according to the proportion of water that they contain.

In the case of the Krakatoa-lavas we have the clearest evidence that when the mixtures of silicates of which they consist contain water, then very fusible glasses are formed. In these circumstances, the earlier formed porphyritic crystals are but little liable to be attacked by the liquid magma in which they float. As the interesting synthetic researches of MM. FOUQUÉ and LÉVY have shown that any particular mineral is liable to separate from a magma when the latter is kept for a long time at a temperature just below the point of fusion of the mineral, we can understand how small is the chance of devitrification taking place in magmas which are liquified at low temperatures, and which, by a small reduction of temperature, become solid.

In other magmas, however, consisting of precisely the same admixture of silicates, *but without water*, we find the fusion-point far higher. The excessively heated magma in such cases exercises the strongest solvent action on the crystals of felspar immersed in it; and in cooling down, much magnetite, augite, enstatite, and felspar separate out from it before it solidifies.

I am convinced that this is a class of questions to which petrologists will have to give much greater attention than they have hitherto done. The characters assumed by an igneous rock depend not only on the peculiar admixture of silicates which compose it, but also on the temperature at which liquefaction and solidification

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* 'Phil. Mag.,' vol. xviii. (1884), p. 22.

could take place in the mass; this being to a great extent dependent on the quantity of water that was present. The temperature at which fusion could take place would largely determine not only the minerals which separated out from the magma, but also the degree and nature of their crystallization. In other words, the texture as well as the mineralogical constitution of the rock would be greatly influenced by the proportion of water present in the magma from which it was formed.

In the same way the actual nature of the volcanic manifestations at any particular vent are seen to be determined, not so much by the mineralogical constitution of the lava, as by the circumstance of the quantity of water contained in the magma. Where this is great, the lava will be perfectly liquid, and will be almost wholly thrown out in the form of pumice and dust. On the other hand, lavas containing little water will require a very high temperature for their fusion, and they will be characterised by great viscosity rather than perfect liquidity.

If, as seems highly probable, the younger ejecta of Krakatoa were formed by the re-fusion of the older lavas, then we can trace the cause of the introduction of water by which their liquefaction by heat was rendered more easy. These older lavas, by the presence in them of hydrous compounds, and by the existence in their cavities of tridymite and other secondary minerals, betray the fact that they have been greatly acted upon by percolating waters. It is through the introduction of the sea and other surface-waters into rock-masses by slow percolation from above, and the consequent formation of new compounds, more readily acted upon by subterranean heat, that I am disposed to regard volcanic phenomena as being brought about. In this we find an explanation of the proximity of volcanoes to great bodies of water, which it seems to me is far more in accord with the actual phenomena than the supposition that water finds access to volcanic foci by means of actual open fissures.

NOTE.—It is very greatly to be regretted that no accurate survey of Krakatoa, and of the surrounding seas was made prior to the great eruption of 1883. Had such been done, a splendid opportunity would have been afforded us for determining whether elevation and subsequent subsidence of the whole mass of the volcano actually occurred. The existing statements concerning the height of the peak of Rakata before and after the eruption are so confused and contradictory (see p. 23 and foot-note), while both the outlines and soundings on the old charts appear to be so untrustworthy, that I fail to detect certain evidence of any movements of the kind. As the phenomena observed at Krakatoa seem to be reconcilable with principles already well established by the study of other volcanoes, I have felt it incumbent on me to adopt such interpretations in preference to those which depend on movements of the volcanic mass which are of a conjectural character.

The theoretical questions, suggested by the study of the Krakatoa-lavas, have been more fully discussed by the author in a paper read before the Geological Section of the British Association at the meeting in Manchester in 1887. The paper is published in the 'Geological Magazine,' Dec. iii., vol. v. (1888), p. 1.

J. W. JUDD.

APPENDIX.

Meteorological Office,
116, *Victoria Street, London, S.W.*

MEMORANDUM.

I have examined the various statements as to the meeting of pumice in the Indian Ocean in the course of the years 1883 and 1884.

With the exception of the masses of floating pumice, often bearing uprooted trees, &c., which blocked the Strait of Sunda and the adjacent harbours of Java and Sumatra, the great majority of entries of the substance come from the region reaching in latitude from the Equator to 20° S., and in longitude from 70° to 100° E.

One observer, Captain REEVES, of the barque *Umvoti*, speaks of two masses—one between 20° and 25° S., the other between 10° and 5° S. These are separated by an interval of clear sea.

Furthermore, a coasting vessel which arrived at Sydney, August 4, 1884, from a voyage round Australia, reported that "all along the north and west coasts of the continent vast shoals of pumice were passed through." This was probably in June or July, 1884.

As the observers almost without exception found the pumice thickly coated with barnacles (*Lepas ansifera*, the common southern species), the material must have been a long time in the water.

We know that Krakatoa was in eruption in May, 1883, and continued more or less active for three months, and as pumice was met with by H.M.S. *Magpie* in 6° S. and 61° E., April 22, 1884, it seems impracticable to trace the course of any particular deposits of this material on the sea surface.

It is, however, interesting to learn that the precise dates of the arrival of pumice on the coasts of Natal, and on the Chagos Islands, were as follows:—

Natal, September 27th and 28th, 1884.
Diego Garcia (Chagos), October 1st, 1884.

As Diego Garcia is in 7° S. and 73° E. (approximately), while Durban is in 30° S. and 31° E., it is not likely that the pumice which reached these two distant stations nearly simultaneously could have been ejected at the same time.

In all discussions of the movements of the pumice it must be remembered that floating bodies will be much affected by the wind, and will not drift solely in accordance with ocean currents.

The deposits of pumice near the coast of Australia may have drifted there before the north-west monsoon, which would prevail in those seas from November, 1883, to March, 1884.

ROBERT H. SCOTT.

A Tabular Statement of the Dates on which, and the Localities where, Pumice or Volcanic Dust was seen in the Indian Ocean in 1883-84. *By* CHARLES MELDRUM, *LL.D., F.R.S.*

(Reprinted, by permission, from the 'British Association Report,' 1885, p. 773.)

Names of Vessels.	Day of Year.	Month and Day.	Hours.	Position at Noon.		Remarks.
				Lat.	Long.	
		1883			E.	
Barque *Actæa* (Capt. Walker)	140 141 141	May 20 ,, 21 ,, 21	2 p.m. to 9 a.m. night	6° 50′ S.	101° 02′	Very fine dust commenced to fall about 2 p.m. The fall continued all night, and stopped about 9 a.m. on the 21st. Small quantities fell again during the night.
Ship *Idomene* (Capt. Johnson)	223	Aug. 11	8 a.m. to 2 p.m.	6 23 S.	88 31	Passed through large fields of pumice.
Barque *West Australian* (Capt. Thomas)	229	,, 17	noon	8 35 S.	91 53	Passed a great amount of floating lava or pumice.
	230	,, 18	noon	9 41 S.	90 28	Passed a great amount of lava to-day.
	231	,, 19	noon	11 08 S.	88 03	Large quantities of pumice; some pieces about 3 feet in diameter.
S.S. *Anerley* (Capt. Strachan)	239	,, 27	—	North Watcher		Ashes began to fall at 10.24 a.m. Showers of ashes and pumice lasted till midnight.
	240	,, 28	—	Anjer Roads		Immense quantities of pumice and débris of all sorts.
Barque *County of Flint* (Capt. J. Rowland)	240	,, 28	noon	8 20 S.	92 04	Great quantity of dust falling; supposed to be coral dust.
French brig *Brani* (Capt. E. Perrot)	240	,, 28	5 a.m.	4 22 S.	91 34	L'atmosphère surchargé de sable. De minuit à 11 heures du matin une très grande quantité de sable très blanc et très fin a couvert toutes les parties accessibles, même presque dans la chambre. Je crois que c'est le résultat d'un orage que

Names of Vessels.	Day of Year.	Month and Day.	Hours.	Position at Noon.		Remarks.
				Lat.	Long.	
		1883		° ′	E. ° ′	
French brig *Brani*—continued.						nous avions observé ces jours derniers sur Sumatra, pendant lequel le tonnerre avait des roulements pareils à une canonnade, et le sable enlevé par cette tourmente a été renvoyé sur nous par la petite brise.
	241	Aug. 29	9 a.m.	5 50 S.	91 20	Il tombe continuellement du sable très fin au point d'obscurcir l'atmosphère.
Barque *Castleton* (Capt. Dioré)	240	,, 28	2 a.m.	5 58 S.	93 30	After a shower of rain the air became loaded with a fine dust, which fell in great quantities on deck. At noon dust still falling. At 2 p.m. dust still falling.
	241	,, 29	6 a.m. 2 p.m.	6 56 S.	93 01	Collected dust off the deck. Pumice-stone floating in the water. At 2 p.m. dust still falling: large quantities of pumice floating past.
Brigantine *Airlie* (Capt. Knight)	252	Sept. 9	6 a.m. 2 p.m.	7 31 S.	103 11	Large quantities of lava. Passing through large quantities of lava.
French barque *Gipsy* (Capt. Martin)	252	,, 9	9 a.m.	4 57 S.	82 06	Grand banc flottant de pierre-ponce pendant toute la journée, suivant le vent comme dans la mer de Sargosse.
French barque *Marie Alfred* (Capt. Brégeon)	263	,, 20	6 a.m.	7 02 S.	101 15	Nous passons dans des bancs successifs et très rapprochés de pierre-ponce.
Barque *Hottenburn* (Capt. Chichester)	286	Oct. 13	4 p.m.	Sunda Strait		Tremendous fields of pumice stopped the vessel.
	287	,, 14	4 a.m.	No obs.		Lots of pumice alongside.
	288	,, 15	midt.	7 19 S.	104 00	Passing large fields of pumice.

Names of Vessels.	Day of Year.	Month and Day.		Hours.	Position at Noon.		Remarks.
					Lat.	Long.	
		1883				E.	
S.S. *Garonne*	294	Oct.	21	9·15 a.m.	10° 15′ S.	78° 07′	Passed through several fields of pumice-stone of various sizes. Some pieces that were picked up had barnacles nearly one inch long adhering to them.
S.S. *Countess of Errol* (Capt. Taylor)	299	,,	26	noon	7 01 S.	104 49	Vast quantities of pumice all round the ship.
	300	,,	27	8 a.m.	8 44 S.	102 40	Sailing through vast quantities of pumice.
Barque *Rollo* (Capt. Currie)	319	Nov.	15	6 a.m.	6 19 S.	88 55	Since daylight sailing through large quantities of pumice. At midnight still large quantities of pumice floating on water.
	320	,,	16	noon	8 04 S.	87 25	Still large quantities of pumice floating past.
	321	,,	17	noon	9 36 S.	85 46	,, ,, ,,
Barque *Eva Joshua* (Capt. Florentin)	332	,,	28	8 a.m.	6 24 S.	64 45	Sailing all day through floating pumice covered with barnacles.
French barque *Henriette* (Capt. A. de Lavit)	336	Dec.	2	5 a.m.	5 42 S.	89 07	Au jour nous avons remarqué que nous étions environnés de pierre-ponce. A 9 heures nous sommes toujours entourés de pierre-ponce.
	337	,,	3	5 a.m.	No obs.		Il y a encore de pierre-ponce.
	338	,,	4	6 a.m.	7 14 S.	87 32	Nous avons encore rencontré de pierre-ponce.
	339	,,	5	9 a.m.	8 44 S.	?	Nous recontrons encore beaucoup de pierre-ponce.
Barque *Ta Lee* (Capt. Stolzce)	336	,,	2	4 p.m.	6 07 S.	81 55	Passed a bank of pumice extending about twenty-five miles; some pieces about two feet square.
	341	,,	7	a.m.	8 59 S.	82 14	Still passing pumice-stone and a kind of ashes.

Names of Vessels.	Day of Year.	Month and Day.	Hours.	Position at Noon.		Remarks.
				Lat.	Long.	
		1883			E.	
Ship *Shah Jehan* (Capt. Williams)	343	Dec. 9	6 a.m.	7° 26′ S.	84° 58′	Noticed the sea covered in streaks with what appeared to be pumice-stone in pieces and in powder; lowered the boat and picked up some; some of the stones covered with barnacles.
	347	,, 13	—	13 47 S.	82 00	Throughout the day the sea covered in streaks with some kind of lava and large-sized lumps of pumice-stone.
	348	,, 14	—	15 03 S.	81 42	Passed a great deal of pumice and lava this day.
	349	,, 15	—	15 30 S.	80 51	Passed a lot of pumice and lava.
Ship *Invercauld* (Capt. Leslie)	346	,, 12	8 a.m.	11 45 S.	87 09	Passed through a quantity of dust seemingly floating on the surface.
	348	,, 14	10 a.m.	9 54 S.	87 56	Passed through a quantity of pumice-stone.
	349	,, 15	a.m.	7 56 S.	89 32	Passed large quantities of pumice-stone.
Barque *Evelyn* (Capt. Stevenson)	354	,, 20	noon	9 40 S.	88 11	Passing great quantities of pumice.
	355	,, 21	?	7 30 S.	88 26	Still passing quantities of pumice.
Barque *May Queen* (Capt. Hugon)	362	,, 28	—	2 14 N.	85 35	Une infinité de parcelles de roche brûlée sur l'eau.
		1884				
Sch. *Lord Tredegar* (Capt. Clarke)	5	Jan. 5	2 p.m.	6 35 S.	68 25	Passed through a quantity of lava.
	8	,, 8	noon	12 12 S.	66 59	,, ,, ,,
	9	,, 9	—	14 56 S.	65 18	Passed through a great quantity of pumice to-day.
	10	,, 10	noon	17 34 S.	63 04	,, ,, ,,

Names of Vessels.	Day of Year.	Month and Day.	Hours.	Position at Noon.		Remarks.
				Lat.	Long.	
		1884			E.	
French barque *Résolu* (Capt. Mouton)	8	Jan. 8	p.m.	7° 05′ S.	84° 01′	Traversé plusieurs bancs de pierre-ponce.
Barque *May Queen* (Capt. Hugon)	9	" 9	a.m.	7 00 S.	83 13	Une infinité de roche brûlée flottant.
	12	" 12	p.m.	11 23 S.	75 46	Une infinité de débris volcaniques.
Ship *Argomene* (Capt. H. Williams)	12	" 12	8 p.m.	7 51 S.	87 05	Passing through large quantities of pumice.
Ship *Roderick Dhû* (Capt. Boldchild)	13	" 13	4 p.m.	13 34 S.	90 50	Passing through large quantities of pumice.
	14	" 14	p.m.	9 25 S.	90 26	" " "
French barque *Eugénie* (Capt. A. Arnaud)	15	" 15	p.m.	6 14 S.	81 40	Beaucoup de pierre-ponce formant de lis allongé à l'ouest.
Barque *Star of Greece* (Capt. W. Legg)	21	" 21	7 a.m.	13 49 S.	85 45	Large quantities of pumice in separate streams from S.E. to N.W. At 6 p.m. still passing large quantities of pumice.
	22	" 22	2 a.m.	13 21 S.	86 06	The streams of pumice-stone stopped.
	23	" 23	midt.	10 45 S.	85 50	A large stream of pumice-stone.
Barque *Eva Joshua* (Capt. Florentin)	22	" 22	p.m.	13 05 S.	66 40	Sighted pumice-stone.
Sch. *Glenesk* (Capt. Feleng)	26	" 26	a.m.	3 19 S.	81 05	Rencontré à chaque instant des bancs formés par des pierres-ponce.
Sch. *Mary Whitridge* (Capt. Howes)	40	Feb. 9	7 a.m.	9 41 S.	88 26	Passing lots of floating pumice-stone.
	41	" 10	5 a.m.	8 11 S.	89 24	" " "
	42	" 11	5 a.m.	5 06 S.	90 11	" " "
	43	" 12	2 a.m.	2 43 S.	91 26	Passing large fields of pumice.

Names of Vessels.	Day of Year.	Month and Day.	Hours.	Position at Noon.		Remarks.
				Lat.	Long.	
		1884			E.	
Barque *County of Flint* (Capt. J. Rowland)	57	Feb. 26	—	1° 27′ S.	86° 53′	Great quantities of pumice, which appears to have been long in the water.
	58	,, 27	—	1 50 S.	87 48	Pumice-stone passing.
	61	March 1	4 a.m.	2 21 S.	85 21	Great quantities of pumice-stone in sight.
	62	,, 2	2 a.m.	2 40 S.	84 31	Great quantities of pumice passing.
	63	,, 3	2 p.m.	2 36 S.	84 10	,, ,, ,,
	65	,, 5	3 a.m.	4 01 S.	83 57	,, ,, ,,
			2 p.m.	—	—	,, ,, ,,
Ship *Parthenope* (Capt. F. Gray)	64	,, 4	—	1 36 S.	87 21	Sea strewed with pumice-stone covered with barnacles.
	65	,, 5	—	2 14 S.	87 21	,, ,, ,,
	66	,, 6	—	3 36 S.	88 04	,, ,, ,,
	70	,, 10	—	5 52 S.	88 16	,, ,, ,,
	72	,, 12	—	10 38 S.	86 09	Sea covered with lava and pumice 2 feet thick.
	75	,, 15	—	17 49 S.	70 40	Sea strewed with lava and pumice.
Ship *Kelvinside* (Capt. Kirkell)	69	,, 9	noon	14 40 S.	81 56	Since 7th been sailing through floating pumice in pieces from the size of a cocoanut to pieces almost like dust.
Barque *Excelsior* (Capt. F. Edgar)	72	,, 12	6 p.m.	20 27 S.	78 09	Great quantities of floating pumice.
Sch. *Iris* (Capt. Shaw)	82	,, 22	p.m.	9 35 S.	76 39	Passing vast quantities of pumice.
	85	,, 25	a.m.	15 33 S.	72 11	,, ,, ,,
Sch. *Northern Bell* (Capt. L. Morris)	84	,, 24	p.m.	26 33 S.	70 00	For four hours passing a vast quantity of pumice-stone covered with barnacles.

Names of Vessels.	Day of Year.	Month and Day.	Hours.	Position at Noon.		Remarks.
				Lat.	Long.	
		1884			E.	
Ship *Invercauld* (Capt. Leslie)	93	April 2	a.m.	00° 06′ S.	90° 30′	Passing through a quantity of pumice.
	97	,, 6	—	4 40 S.	91 13	During last five days passed through a quantity of pumice-stone, of a greenish colour and covered with barnacles and crabs.
Barque *Evelyn* (Capt. Stevenson)	102	,, 11	a.m.	2 10 S.	90 13	Passing quantities of pumice-stone.
Barque *Peggie Doy* (Capt. Hill)	106	,, 15	a.m.	11 34 S.	59 02	Passed large quantities of pumice.
	112	,, 21	a.m.	16 55 S.	58 22	Passed quantities of pumice.
S.S. *Madagascar* (Capt. A. Vielle)	120	,, 29	p.m.	18 22 S.	57 16	Several pieces of pumice floating alongside.
Ship *Knight Commander* (Capt. Bell)	120	,, 29	a.m.	16 38 S.	72 19	Passed through fields of pumice-stone and scoriæ.
Barque *Caller Ou* (Capt. Rae)	125	May 4	a.m.	11 07 S.	62 41	Sailing through quantities of lava.
Lugger *Success* (Capt. Hazel)	125	,, 4	—	10 16 S.	62 35	Depuis plusieurs jours la mer est couverte de pierre et de sable volcanique d'une couleur jaunâtre.
Ship *Knight Companion* (Capt. Davis)	136	,, 15	a.m.	10 32 S.	88 53	Passing through quantities of pumice.
Barque *Iris* (Capt. Evans)	145	,, 24	p.m.	5 21 S.	94 44	A great quantity of floating pumice.
French barque *Louise Collet* (Capt. Beckman)	152	,, 31	a.m.	12 43 S.	81 29	On rencontre toujours des pierres-ponce.
Brig *Flora* (Capt. Menton)	152	,, 31	p.m.	10 18 S.	58 09	Le capitaine tombe à la mer en pêchant des pierres-ponce.
Ship *Broomhall* (Capt. Grieve)	165	June 13	2 p.m.	5 29 S.	89 39	Passing through quantities of pumice covered with barnacles.

Names of Vessels.	Day of Year.	Month and Day.		Hours.	Position at Noon.		Remarks.
					Lat.	Long.	
		1884				E.	
Brig *Rio Loge* (Capt. Lovett)	169	June	17	noon	11° 29′ S.	126° 29′	Passed large quantities of pumice.
	169	,,	17	4 p.m.	—	—	,, ,, ,,
	175	,,	23	6 a.m.	14 39 S.	113 36	,, ,, ,,
	175	,,	23	6 p.m.	—	—	,, ,, ,,
	176	,,	24	5 p.m.	15 16 S.	110 08	,, ,, ,,
	177	,,	25	6 p.m.	16 07 S.	106 51	,, ,, ,,
Sch. *Iris* (Capt. Shaw)	183	July	1	2 a.m.	17 08 S.	114 33	Passing vast quantities of pumice.
Ship *Reigate* (Capt. Ritchie)	190	,,	8	7 a.m.	4 25 S.	93 47	Passed through large quantities of pumice.
Barque *Northern Star* (Capt. Evans)	207	,,	25	4 a.m.	13 42 S.	113 42	Large quantities of pumice floating on the water.
	208	,,	26	4 a.m.	14 46 S.	109 43	,, ,, ,,
Sch. *Catherine Marie* (Capt. Stubington)	210	,,	28	7 a.m.	23 36 S.	59 40	Passed through quantities of pumice varying in size from an orange to a walnut shell. Picked up some pieces covered with barnacles and limpets.
Barque *City of Tanjore* (Capt. Sinclair)	222	Aug.	9	4 p.m.	14 45 S.	111 20	Passed small pieces of pumice.
	223	,,	10	noon	15 28 S	108 12	Sailing through large quantities of pumice floating in streaks like Gulf-weed.
	224	,,	11	5 a.m.	16 05 S.	104 53	Still sailing through quantities of pumice.
	225	,,	12	8 a.m.	16 00 S.	101 56	Still sailing through pumice.
	226	,,	13	4 p.m.	16 04 S.	99 05	,, ,, ,,
	227	,,	14	4 p.m.	16 06 S.	96 16	Less pumice to-day.

Names of Vessels.	Day of Year.	Month and Day.	Hours.	Position at Noon.		Remarks.
				Lat.	Long.	
		1884			E.	
Sch. *Jasper* (Capt. Stannard)	228	Aug. 15	a.m.	23° 06′ S.	61° 47′	Passed several pieces of floating pumice.
	230	,, 17	a.m.	20 56 S.	61 01	,, ,, ,,
Barque *Marion Neil* (Capt. Paterson)	239	,, 26	8 a.m.	14 09 S.	108 06	A lot of pumice-stone floating past.
	240	,, 27	6 a.m.	14 36 S.	106 39	,, ,, ,,
	243	,, 30	8 a.m.	15 19 S.	100 30	,, ,, ,,
Barque *Jane Maria* (Capt. Griffiths)	245	Sept. 1	7.30 a.m. to noon	9 10 N.	112 11	Passed through a quantity of very small pumice-stone.
Sch. *Coleridge* (Capt. Marshall)	261	,, 17	noon	21 15 S.	50 20	Several pieces of floating pumice.
	262	,, 18	4 p.m	20 39 S.	51 10	Passed large quantities of pumice which, apparently, had been a long time in the water.
	263	,, 19	noon	20 04 S.	52 24	,, ,, ,,
Barque *Caller Ou* (Capt. Rae)	271	,, 27	8 a.m.	7 20 S.	93 02	Much lava floating about.
S.S. *Castlebank* (Capt. Chevalier)	272	,, 28	3 p.m.	8 39 S.	68 31	Passed through large quantities of pumice, which seems to have been a long time in the water.
Barque *Jane Maria* (Capt. Griffiths)	284	Oct. 10	p.m.	6 58 S.	102 54	Passed a large quantity of floating pumice.
	287	,, 13	3.30 p.m.	10 44 S.	93 57	Passed a large quantity of very small pumice.
	288	,, 14	5 a.m.	12 33 S.	90 19	,, ,, ,,
	288	,, 14	5 p.m.	—	—	Large and small pieces of pumice seen frequently during the afternoon.
French barque *France Chérie* (Capt. Lavary)	290	,, 16	—	15 09 S.	109 59	Depuis plusieurs jours la mer est couverte de pierre-ponce.
	316	Nov. 11	—	20 21 S.	58 55	J'ai parcouru environ une étendue de 1,200 milles par latitude sud où j'ai rencontré beaucoup de pierre-ponce.

PLATE II.

Fig. 1.—This drawing is reproduced from one in VERBEEK'S 'Atlas,' which was taken in October, 1883. It shows the slopes of the portion of the peak of Rakata which remained standing after the great outburst, covered with enormous masses of pumice and dust. In this covering, streams have already cut out a series of anastomosing channels, while the action of the sea has given rise to the formation of a cliff.

Fig. 2.—This is based in part on the beautiful coloured drawing in VERBEEK'S 'Atlas,' also made in October, 1883, and in part on the photograph subsequently obtained (June, 1886), when some details before invisible were rendered apparent by the washing of the surface by rain. It must be remembered that the surface looked at is not a vertical plane lying in one azimuth, but consists of two planes meeting in the central line at an angle of about 135°, and inclining from the vertical by about 30°. The lowest, nearly horizontal, beds belong to the oldest ejections of the volcano, andesite with tridymite. The lava-currents, tuff beds, and dykes of the mass of the volcano are composed of different varieties of basalt. A study of these shows that lateral eruptions must have taken place on the flanks of the cone, and that, as in the case of Etna, there must have been a shifting in the axis of the cone. The central dyke seems to indicate that the last eruption from this cone must have consisted of an andesitic material.

For the skilful drawing of this Plate, and of Plate III., I am indebted to Mr. A. E. TUTTON.

FIG. 2.—*Krakatoa, after the Eruption, as seen from the North.*

FIG. 1.—*Krakatoa, after the Eruption, as seen from the South-east.*

A. E. TUTTON, del.

TYPO-ETCHING CO., Sculpt.

PLATE III.

SECTIONS OF THE LAVAS OF KRAKATOA.

Fig. 1.—Section of the older andesite of Krakatoa, as seen when magnified 25 diameters. A portion of the slide has been chosen where the crystals of felspar, enstatite, augite, and magnetite are more crowded together than is usually the case. The reddish tint of the base when seen by reflected light is due to the incipient decomposition of magnetite grains and the formation of the hydrated ferric oxides.

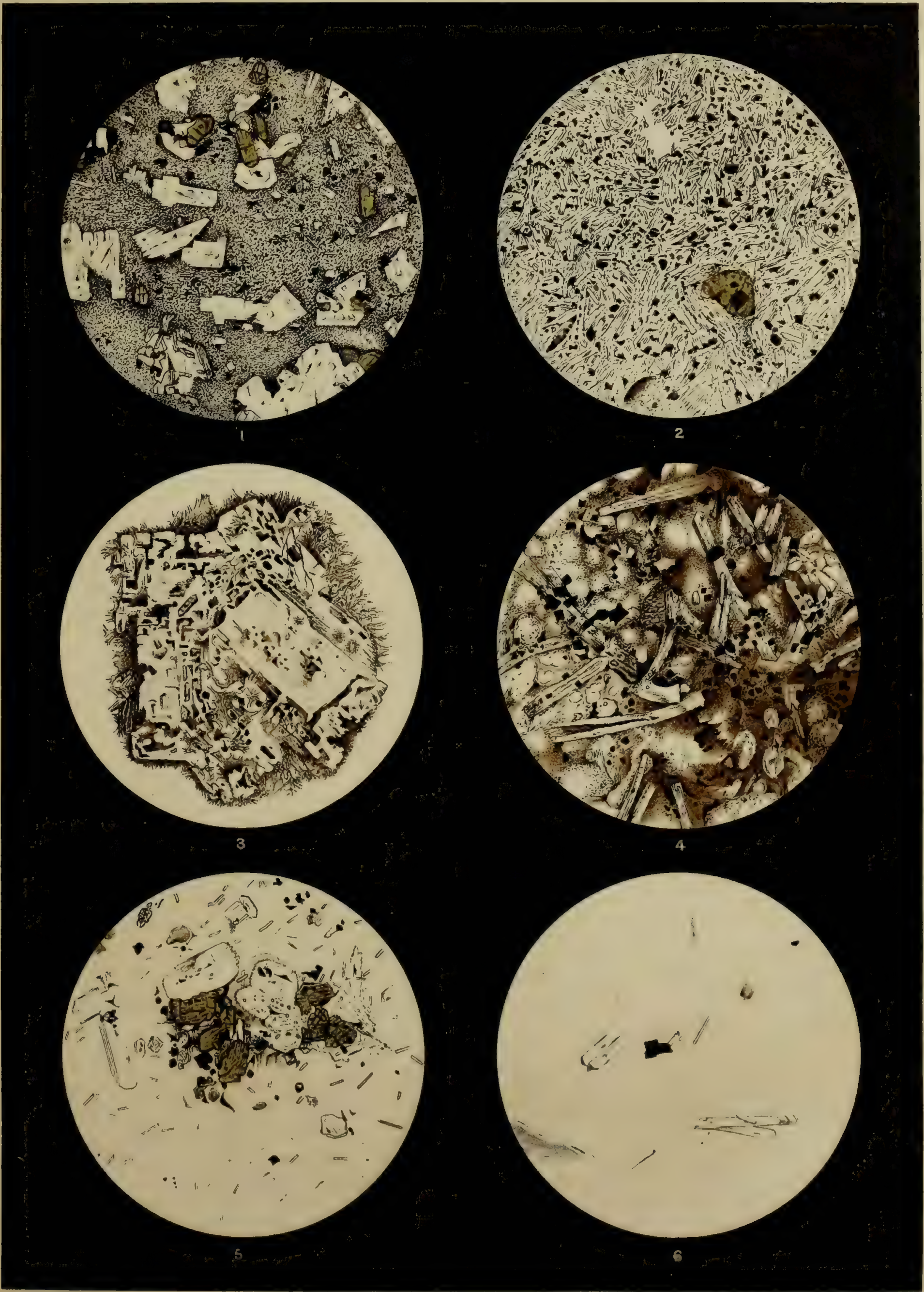
Fig. 2.—Portion of the base of the same rock, as seen when magnified 250 diameters. Microlites of felspar, tridymite (?), and magnetite abound, and with some of pyroxene and hornblende (?), make up a stony base. Cavities lined with tridymite, quartz, and hornblende are seen in this base.

Fig. 3.—Zoned and much corroded crystal of felspar, magnified 35 diameters, from the porphyritic pitchstone of Krakatoa. Such crystals, in which the glass inclusions are in great part, if not entirely, of secondary origin, abound in this rock. In some cases, as shown by the figure, their continuity with the enveloping glass is clearly apparent.

Fig. 4.—Glassy base of the porphyritic pitchstone magnified 250 diameters. The abundant separation of granules of magnetite all through the glass which envelopes the microlites of felspar and magnetite is very well seen in this section.

Fig. 5.—Section of the porphyritic obsidian of Krakatoa, as seen magnified 25 diameters. The pale brown glass, with a few scattered microlites, has in its midst a group of crystals, felspar, enstatite, augite, and magnetite, with some of the darker-coloured and less fusible glass still adhering to them.

Fig. 6.—Portion of the base of the same rock as the last, as seen magnified 250 diameters. The sparsity of the microlites of felspar, pyroxene, and magnetite in the very glassy base is well illustrated by this section.



A. E. Hutton, del. Parker & Coward, lith.

[illegible] & Co. imp

Sections of the Rocks of Krakatoa.

PLATE IV.

THE PUMICE AND DUST OF KRAKATOA.

Fig. 1.—Section of pumice thrown out during the earlier portion of the Krakatoa eruption (May, 1883), cut in the direction of the drawn-out fibres of the mass. This pumice was much finer in grain than the bulk of the Krakatoa pumice, and contained no porphyritic crystals. It is represented as seen with a magnifying power of 50 diameters.

Fig. 2.—Cross section of the same pumice, magnified 50 diameters.

Fig. 3.—Section of common pumice of Krakatoa, as seen with a magnifying power of 50 diameters. In the midst is seen a group of crystals of felspar, enstatite, and magnetite. In this pumice the structure is much coarser than in that represented in Figs. 1 and 2, and large irregular air-cavities abound in it.

Fig. 4.—Section of artificial pumice, as seen magnified 50 diameters, made by fusing the porphyritic obsidian of Krakatoa. The escaping gases distend the mass, producing a pumice quite similar in appearance to the common pumice of Krakatoa. A porphyritic crystal of felspar is seen near the middle of the slide.

Fig. 5.—Pumice-dust, which fell on board the *Arabella* when about 1,100 English miles distant from the volcano. The forms of the particles of pumice are well seen. In this dust, which fell at a great distance from the volcano, fragments of the crystallised minerals become few and inconspicuous. The particles are shown as seen with a magnifying power of 250 diameters.

Fig. 6.—Similar material, formed by triturating the common Krakatoa pumice in a mortar, as seen with magnifying power of 250 diameters.

Parker & Coward del et lith
West Newman & Co imp

Pumice and Dust of Krakatoa

CHART SHOWING WHEN AND WHERE PUMICE OR VOLCANIC DUST WAS SEEN IN THE INDIAN OCEAN

FROM AUG. TO DEC. 1883. – THE PLACE OF OBSERVATION IS SHOWN THUS ○, THE DATE IS GIVEN BY THE DAY OF THE YEAR THUS ○ 300 27TH OCT.

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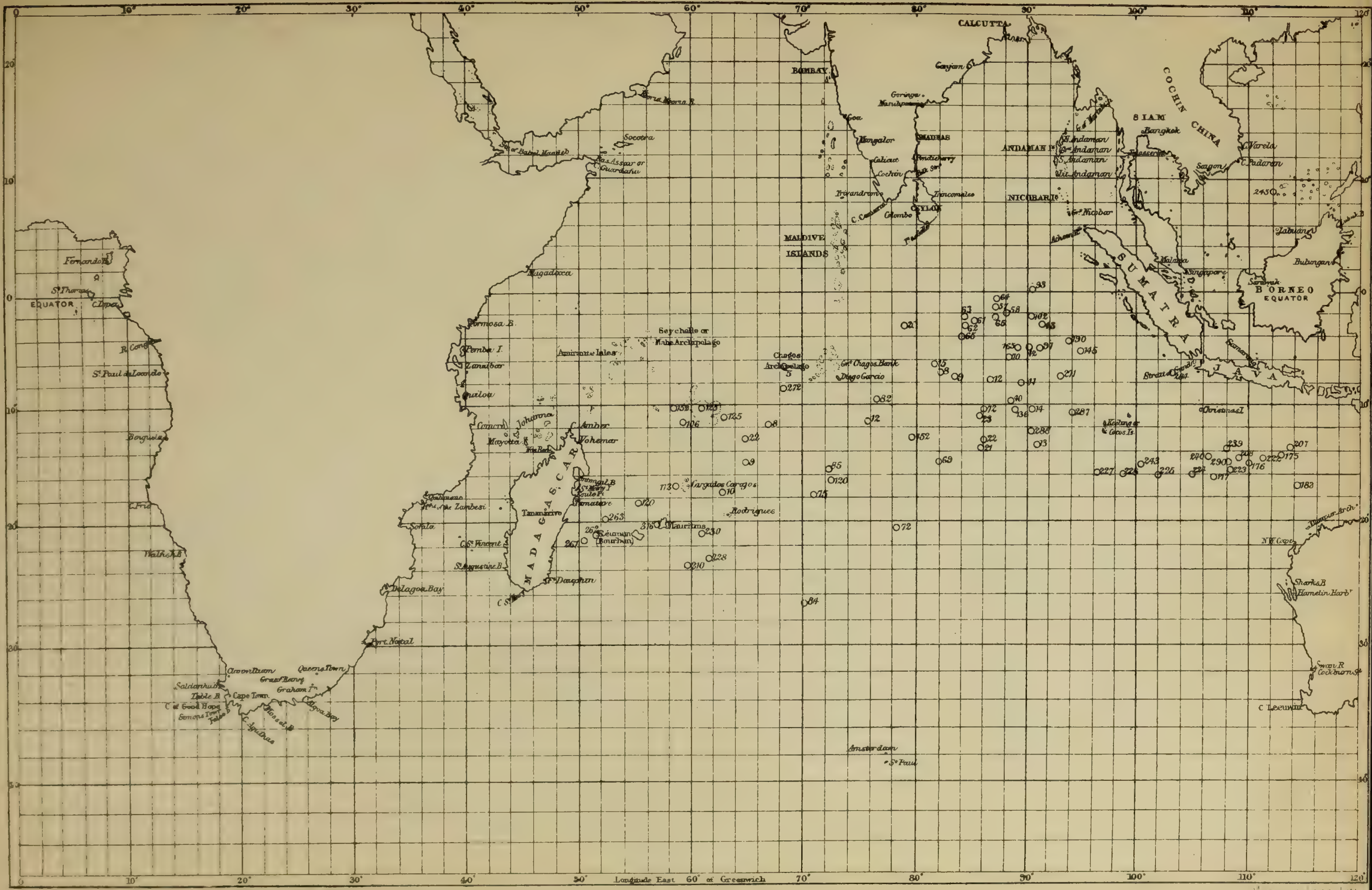
CHART SHOWING WHERE AND WHEN PUMICE OR VOLCANIC DUST WAS SEEN IN THE INDIAN OCEAN FROM JAN. 1884 TO NOVEMBER 1884.



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Malby & Sons, Lith.

PART II.

ON THE AIR WAVES AND SOUNDS CAUSED BY THE ERUPTION OF KRAKATOA IN AUGUST, 1883.

Prepared in the Meteorological Office,

AND

Presented by Lieut.-General R. STRACHEY, *F.R.S., Chairman of the Meteorological Council.*

SECTION I.—AIR WAVES.

NOTES on this subject were presented to the Royal Society in December, 1883,* but since that date observations made at many other places, besides those first discussed, have been obtained, and the available records may now be regarded as complete.

At the desire of the Committee appointed by the Royal Society to collect information relating to the eruption of Krakatoa, which occurred in August, 1883, the present report has been drawn up in the Meteorological Office, under the general supervision of the Chairman of the Meteorological Council, the details having been worked out by Mr. R. H. CURTIS, one of the senior clerks in the Meteorological Office, Mr. C. THOMPSON assisting him in the preparation of the accompanying curves and diagrams.

The stations from which barometrical or other registers supplying evidence of the disturbance, have been received, with the nature of the register and of the recording instrument, the general character of the data, and the period over which the observations extend, in each case, are shown in the annexed Table I.

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* "Note on a Series of Barometrical Disturbances which passed over Europe between the 27th and 31st of August, 1883," by Robt. H. Scott, F.R.S., Secretary to the Meteorological Council; and "Note on the Foregoing Paper," by Lieutenant-General Strachey, F.R.S. Printed in the 'Proceedings of the Royal Society,' No. 229, vol. xxxvi., pp. 139–151.

TABLE I.

Stations from which barometrical or other observations have been received, with a description of the recording instruments and data.

Station.	Data received, and nature of recording instrument.	General character of data.	Duration of Record—Greenwich Civil Time.	
			From	To
Batavia ..	Continuous automatic record of gasometer indicator.	Open scale and clear record.	2 p.m., 26th Aug.	Noon, 28th Aug.
Batavia ..	Hourly observations of barometer and thermometer.	.. .. ..	1 a.m., 21st Aug.	Midnight, 31st Aug.
Manila ..	Hourly observations of pressure, temperature, wind, &c.	.. .. ..	1 a.m., 20th Aug.	Midnight, 10th Sept.
Melbourne ..	Photographic copy of record from a "Kew pattern" photo-barograph, and also tracing of record of a "King" barograph.	Time, scale, &c., very open, and copies carefully made.	10 a.m., 25th Aug.	10 a.m., 30th Aug.
Sydney ..	Tracing of record obtained from an electrical barograph (two copies).	Very open scale, showing clearly some small movements; trace carefully made.	9 a.m., 24th Aug.	9 a.m., 31st Aug.
Dunedin ..	Tracing of a "Richard" barograph record.	Scale not very open, and tracing rather roughly made.	9 a.m., 27th Aug.	9 a.m., 3rd Sept.
Wellington, N.Z.	Tracing of a "Richard" barograph record.	Scale not very open, and tracing rather roughly made.	Noon, 27th Aug.	10 a.m., 3rd Sept.
South Georgia	Tracing of a "Sprung" barograph record.	Time scale rather contracted; tracing carefully made.	9 a.m., 26th Aug.	7 a.m., 2nd Sept.
Loanda ..	Tracing of a "Richard" barograph record.	Scale small, but copy carefully made.	10 a.m., 27th Aug.	10 a.m., 3rd Sept.
Mauritius ..	Photographic copy of record obtained from a "Kew pattern" photo-barograph.	Time scale, &c., sufficiently open, and copy very good.	Noon, 26th Aug.	7 a.m., 1st Sept.
Bombay ..	Photographic copy of record obtained from a "Kew pattern" photo-barograph.	Time scale, &c., good, and copy very good.	10 a.m., 26th Aug.	10 a.m., 1st Sept.
Calcutta ..	Tracing of record from a "Kew pattern" photo-barograph; also zincographed copy of curve.	Time scale, &c., good; tracing carefully made.	10 a.m., 26th Aug.	8 a.m., 1st Sept.

TABLE I.—*continued.*

Station.	Data received, and nature of recording instrument.	General character of data.	Duration of Record—Greenwich Civil Time.	
			From	To
Zi-Ka-Wei .. (Shanghai.)	Tracing of record from a "Kew pattern" photo-barograph for 1st and 2nd oscillations, and also of record from a "Secchi" balance barograph for 1st to 3rd oscillations.	Scale of "Secchi" instrument very open, except for time, which is contracted; scale of photo curve good; tracings carefully made.	2 a.m., 22nd Aug.	6 p.m., 29th Aug.
Tokio.. ..	Tracing of record from a "King" barograph.	Very open scale, and tracing very carefully made.	9 a.m., 27th Aug.	9 a.m., 2nd Sept.
Tiflis	Hourly readings of the barometer.	.. .. ..	1 a.m., 26th Aug.	Midnight, 2nd Sept.
Pawlowsk ..	Tracing of the curve from a "Hasler" barogragh.	Trace not continuous, instrument registers only at 10 min. intervals; carefully traced.	Midnight, 25th Aug.	Midnight, 30th Aug.
St. Petersburg.	Tracing of the curve from a "Hasler" barograph.	Trace not continuous, scale open, and tracing apparently carefully made.	6 p.m., 26th Aug.	Midnight, 30th Aug.
Cracow ..	Lithographed copy of trace from a "Kreil" barograph.	Scale not very open; trace shows scarcely any signs of disturbance.	Noon, 27th Aug.	Noon, 1st Sept.
Buda-Pesth ..	Lithographed copy of barogram.	Scales open, and oscillations clearly shown.	Midnight, 26th Aug.	Midnight, 30th Aug.
Vienna ..	Original barograms from a "Kreil" barograph.	Record at 5 min. intervals; scales fairly open.	Noon, 27th Aug.	Noon, 29th Aug.
Berlin ..	Copy of barograms	Record at 15 min. intervals; time scale rather contracted.	Noon, 26th Aug.	Noon, 5th Sept.
Leipsic ..	Copy of barograms	Very open scales	11 a.m., 27th Aug.	5 p.m., 31st Aug.
Magdeburg ..	Lithographed copy of a "Sprung" barograph record.	Good, but time scale rather contracted.	Midnight, 26th Aug.	Midnight, 1st Sept.
Munich ..	Lithographed copy of a "Richard" barograph record.	Good record, but time scale very contracted.	Midnight, 26th Aug.	3 a.m., 31st Aug.
Milan.. ..	Hourly readings of barometer and wind.	.. .. ..	Noon, 25th Aug.	11 a.m., 1st Sept.
Modena ..	Lithographed enlarged copies of barometer curves.	Curves have been very much enlarged from the originals, and have very open scales.	Noon, 26th Aug.	Noon, 3rd Sept.

TABLE I.—*continued.*

Station.	Data received, and nature of recording instrument.	General character of data.	Duration of Record—Greenwich Civil Time.	
			From	To
Rome.. ..	Tracing of a "Richard" barograph record.	Very clear, but scales small	Noon, 20th Aug.	Noon, 2nd Sept.
Palermo ..	Tracing of a "Secchi" barograph curve.	Trace carefully made, but time scale very contracted.	7 a.m., 24th Aug.	7 a.m., 5th Sept.
San Fernando .	Photographic copy of record from barograph made by Salleron, of Paris.	Open scale and very good curve, but the time is doubtful.	10 a.m., 26th Aug.	10 a.m., 30th Aug.
Lisbon ..	Tracing of a "Rèdier" barogram.	Very contracted time scale, but clearly traced.	Midnight, 25th Aug.	Midnight, 30th Aug.
Serra da Estrella.	Tracing of a "Richard" barograph record.	Small time scale	8 a.m., 27th Aug.	6 a.m., 31st Aug.
Coimbra ..	Original curve of a "Kew pattern" photo-barograph.	Very good curves, and open scales.	Midnight, 26th Aug.	Midnight, 30th Aug.
Paris— Parc St. Maur	Tracing of curve of a "Redier" barograph, with hourly readings of barometer.	Time scale rather contracted, but movements clearly shown and trace carefully made.	Midnight, 25th Aug.	Midnight, 30th Aug.
Montsouris..	Trace of record obtained from a balance barometer.	Oscillations very well shown, but time scale rather contracted.	Midnight, 25th Aug.	Noon, 29th Aug.
Brussels ..	Lithographed copy of record from a photo-barograph.	Good clear trace	8 a.m., 26th Aug.	8 a.m., 1st Sept.
Greenwich ..	Tracing and photographic copy of record of photo-barograph.	Open scales, and very good copies.	Noon, 26th Aug.	Noon, 2nd Sept.
Kew	Original curve from a "Kew pattern" photo-barograph.	Open scales, and good curves	Midnight, 26th Aug.	Midnight, 1st Sept.
Geldeston ..	Tracing of record from a "Redier" barograph.	Open scales, and traces carefully made.	Midnight, 25th Aug.	Midnight, 2nd Sept.
Oxford ..	Original curve of a "Kew pattern" photo-barograph.	Open scales, and good curves	10 a.m., 25th Aug.	10 a.m., 31st Aug.
Falmouth ..	Original curve of a "Kew pattern" photo-barograph.	Open scales, and good curves	Midnight, 26th Aug.	Midnight, 1st Sept.
Valencia ..	Original curve of a "Kew pattern" photo-barograph.	Open scales, and good curves	Midnight, 26th Aug.	Midnight, 1st Sept.
Armagh ..	Original curve of a "Kew pattern" photo-barograph.	Open scales, and good curves	Midnight, 26th Aug.	Midnight, 1st Sept.

TABLE I.—*continued.*

Station.	Data received, and nature of recording instrument.	General character of data.	Duration of Record—Greenwich Civil Time.	
			From	To
Liverpool ..	Tracings of record of a "King" barograph.	Very open scales, and carefully traced copies.	9 a.m., 27th Aug.	9 a.m., 4th Sept.
Stonyhurst ..	Original curve of a "Kew pattern" photo-barograph.	Open scales, and good curves	Midnight, 26th Aug.	Midnight, 1st Sept.
Glasgow .	Original curve of a "Kew pattern" photo-barograph.	Open scales, and good curves	Midnight, 26th Aug.	Midnight, 1st Sept.
Aberdeen ..	Original curve of a "Kew pattern" photo-barograph.	Open scales, and good curves	Midnight, 26th Aug.	Midnight, 1st Sept.
Toronto ..	Photographic copy of record of a "Kew pattern" photo-barograph.	Open scales, and good copies of traces.	Noon, 26th Aug.	Noon, 3rd Sept.
New York ..	Copies of record obtained from a "Draper" pencil barograph.	Open scale, and clear trace..	Midnight, 25th Aug.	Midnight, 1st Sept.
Hastings-on-Hudson, N.Y.	Copy of record obtained from a "Draper" barograph.	Very contracted time scale; clear trace.	3 p.m., 26th Aug.	3 p.m., 2nd Sept.
Washington ..	Copies of trace from a "Gibbon" electric barograph.	Very open scales, and careful copies.	Noon, 26th Aug.	Noon, 2nd Sept.
Mexico ..	Copy of trace from barograph, apparently an aneroid recording only hourly.	Very small time scale; trace not continuous, given at the hours only.	1 a.m., 26th Aug.	11 p.m., 2nd Sept.
Havana ..	Original records of barograph, anemograph, thermograph, &c.	Time scale very contracted, and barometer trace somewhat thick, but the earlier oscillations are well shown.	Noon, 23rd Aug.	Noon, 6th Sept.
Cordoba ..	Curve of hourly readings obtained from an hourly-recording aneroid.	Trace interpolated between the hours.	Midnight, 25th Aug.	Midnight, 2nd Sept.

The geographical position of the stations from which the *continuous* barometric registers have been received, and which supply the data now exclusively dealt with, their latitudes, longitudes, and distances from Krakatoa, in degrees of a great circle, are shown in the following Table II.

TABLE II.

Geographical position of Krakatoa, and of the principal Stations from which data have been supplied.

Station.	Latitude.	Longitude.	Distance in Degrees of a Great Circle from Krakatoa.	
			Direct.	Through Antipodes.
	° ′	° ′	° ′	° ′
Krakatoa	6 9 S.	105 22 E.	..	..
Batavia	6 9 S.	106 48 E.	1 22	358 38
Melbourne	37 50 S.	144 58 E.	47 53	312 7
Sydney	33 54 S.	151 14 E.	50 33	309 27
Dunedin	45 52 S.	170 37 E.	68 27	291 33
Wellington, N.Z.	41 16 S.	174 47 E.	70 31	289 29
South Georgia	54 31 S.	36 6 W.	111 22	248 38
Loanda	8 49 S.	13 7 E.	91 17	268 43
Mauritius	20 6 S.	57 33 E.	48 29	311 31
Bombay	18 54 N.	72 49 E.	40 42	319 18
Calcutta	22 33 N.	88 21 E.	33 8	326 52
Zi-Ka-Wei	31 12 N.	121 26 E.	40 22	319 38
Tokio	35 41 N.	139 46 E.	52 41	307 19
Pawlowsk	59 41 N.	30 29 E.	87 49	272 11
St. Petersburg	59 56 N.	30 18 E.	87 57	272 3
Buda-Pesth	47 30 N.	19 2 E.	92 5	267 55
Vienna	48 12 N.	16 22 E.	93 58	266 2
Berlin	52 30 N.	13 19 E.	96 7	263 53
Leipsic	51 20 N.	12 24 E.	96 36	263 24
Magdeburg	52 9 N.	11 38 E.	97 10	262 50
Munich	48 9 N.	11 34 E.	97 6	262 54
Modena	44 38 N.	10 55 E.	97 30	262 30
Rome	41 54 N.	12 29 E.	96 15	263 45
Palermo	38 7 N.	13 21 E.	95 20	264 40
San Fernando	36 28 N.	6 13 W.	111 1	248 59
Lisbon	38 42 N.	9 8 W.	112 52	247 8
Coimbra	40 13 N.	8 26 W.	112 3	247 57
Serra da Estrella	40 25 N.	7 35 W.	111 25	248 35
Paris—				
Parc St. Maur	48 48 N.	2 31 E.	103 10	256 50
Montsouris	48 49 N.	2 20 E.	103 10	256 50
Brussels	50 52 N.	4 21 E.	101 43	258 17
Greenwich	51 29 N.	0 0	104 20	255 40
Kew	51 28 N.	0 19 W.	104 32	255 28
Geldeston	52 28 N.	1 32 E.	103 16	256 44
Oxford	51 46 N.	1 16 W.	105 2	254 58
Falmouth	50 9 N.	5 4 W.	107 45	252 15
Valencia	51 55 N.	10 18 W.	110 29	249 31
Armagh	54 21 N.	6 39 W.	107 44	252 16
Liverpool	53 24 N.	3 4 W.	105 52	254 8
Stonyhurst	53 51 N.	2 28 W.	105 24	254 36
Glasgow	55 53 N.	4 18 W.	106 2	253 58
Aberdeen	57 10 N.	2 6 W.	104 32	255 28
Toronto	43 39 N.	79 23 W.	142 12	217 48
New York	40 43 N.	74 0 W.	145 24	214 36
Washington	38 54 N.	77 2 W.	147 12	212 48
Havana	23 10 N.	82 22 W.	161 20	198 40
Mexico	19 25 N.	99 5 W.	153 24	206 36

The general features of the remarkable atmospheric disturbance caused by the great explosion on the morning of August 27th, which appears to have been the effect of the final paroxysm of the volcano, and of which alone well-defined indications susceptible of identification and measurement have been preserved by the barometric registers, will be seen from Plate VII., which reproduces, on an enlarged scale, the forms of the trace obtained at selected stations where the record is most nearly perfect, on the several successive repetitions of the great aërial oscillation, of which, in many cases, *seven* were distinctly observed. For some time before the great catastrophe, minor explosions occurred, of which indications may be found in many of the photographic registers, especially those from the stations least removed from Krakatoa, the trace being, so to speak, *roughened* by many small irregularities, giving it an appearance very different from that of the smooth line which is its usual character.

In the communication on this subject before made to the Royal Society, it was shown that the observed facts clearly established that the successive repetitions of the disturbance at the numerous stations, after varying intervals of time, were caused by the passage over them of an atmospheric wave or oscillation, propagated over the surface of the globe from Krakatoa as a centre, and thence expanding in a circular form, till it became a great circle at a distance of 180° from its origin; after which it advanced, gradually contracting again, to a node at the antipodes of Krakatoa; whence it was reflected or reproduced, travelling backwards again to Krakatoa, from which it once more returned in its original direction; and in this manner its repetition was observed not fewer than seven times at many of the stations, four passages having been those of the wave travelling from Krakatoa, and three those of the wave travelling from its antipodes, subsequently to which its traces were lost.

The barometric disturbance caused by the great explosion began with a more or less sudden rise, on the summit of which two or three minor oscillations are visible, followed by a deep depression, which was succeeded by a less well marked rise, and by other depressions and rises, the whole disturbance extending over a period of nearly two hours. Such are the characters of the traces of almost all the self-recording instruments on the occurrence of the first two waves, and they are very clearly seen in the photographic barograms obtained at Bombay, Melbourne, Mauritius, and the British Observatories. The traces of these two passages of the wave are, in many instances, remarkably alike, although the second oscillation must have crossed the first at or near the Antipodes of Krakatoa. The wave, however, gradually became deformed during its progress from and to the point where it originated, and eventually lost the characters above described. On the third and fourth recurrence the disturbance is commonly indicated by a sudden rise, which has the appearance of replacing the deep central depression of the first and second passages.

From the irregularity of the form of the wave, and its want of persistency, together with the considerable time over which it extended, there has been some unavoidable uncertainty in fixing the exact moment of the passage of the same phase of the disturbance in the several waves over the various stations ; but the deep depression which immediately followed the initial rise appears, on the whole, to be the most persistent and easily recognised feature in the first two passages of the wave ; and where it can be identified it has been taken as the standard to which reference has been made, especially in fixing the time of the occurrence of the great explosion.

There can, however, be no doubt that the *rise* of the barometer, indicating a sudden increase of pressure, was the first and direct result of the explosion, and that the succeeding fall of the barometer, or decrease of pressure, together with all the subsequent oscillations, were mechanical consequences of the original shock, which in the nature of the case required some considerable time for their development. These remarks have an obvious bearing on the manner in which the exact time of the final explosion may be inferred from the observed times of the atmospheric disturbances, a point to which attention will subsequently be given.

It may here be remarked that the theoretical investigations of Lord RAYLEIGH indicate that the sudden expansion of an elastic gas, supposed to be confined in a spherical envelope, would cause an oscillation which begins with a wave of compression, followed by one of expansion ; a form which appears to correspond with that of the disturbance now under consideration. According to the same authority the amplitude of the wave diminishes as the square root of the distance travelled by it. The data do not admit of any positive opinion being formed as to whether this held good in the present case, but there is at least nothing to suggest any departure from such a law.

Plate VIII. gives a representation, on a *reduced* and uniform scale of time and vertical extent, of the observed disturbances as shown on the various barograms, at the different stations at which the registers are sufficiently well defined for reproduction in this manner. The positions on the traces which have been taken to indicate the standard point of the oscillation, selected as before explained, are marked for facility of reference ; but it must be explained that the reduction of the trace in most cases renders the identifications far less obvious than they actually are on the original registers.

The times at which the successive passages of the wave were observed at the several stations (reckoned in all cases in hours and minutes from 0 hours of the 27th of August, 1883, Greenwich Mean Time, civil reckoning) are shown in the annexed tables.

Table III. gives the times of passage of the waves travelling from Krakatoa towards its antipodes. These passages of the waves are, for convenience, numbered as I., III., V., and VII.

TABLE III.

Observed times of the successive passages of the waves travelling from Krakatoa towards its Antipodes; reckoned from 0 hours of August 27th, 1883, Greenwich Mean Time, civil reckoning.

Station.	Passage of Wave.							
	I.		III.		V.		VII.	
	hrs.	min.	hrs.	min.	hrs.	min.	hrs.	min.
Melbourne	8	14	43	12	..		..	
Sydney	8	24	43	18	78	39	..	
Dunedin	10	15	45	15		?		?
Wellington, N.Z.	10	20	45	45		?		?
South Georgia	15	24	48	24		?		?
Loanda	12	18	47	15	82	23	117	23
							mean.	
Mauritius	8	17	42	50	77	25	112	10
Bombay	7	26	44	0		?		?
Calcutta	6	47	43	22 ?		?		?
Zi-Ka-Wei	7	27	42	54 ?	..		..	
Tokio	8	51	44	12 ?		?		?
Pawlowsk	12	18	49	18	85	38	..	
St. Petersburg	12	14	48	39	85	44 ?	..	
Buda-Pesth	12	30	48	55	84	45 ?	..	
Vienna	12	34	49	9 ?	..		..	
					mean.			
Berlin	12	52	49	37	86	14	122	37 ?
Leipsic	14	0 ?		?		?	..	
Magdeburg	12	59	49	28	84	31		?
Munich	12	35	49	30	85	0	..	
Modena	12	51*	49	11*	85	26*	121	36*
Rome	13	0	48	55		?		?
Palermo	13	37 ? †		?		?		?
San Fernando	13	22	49	12	..		..	
Lisbon	14	17	50	12		?	..	
Serra da Estrella	13	50 ?	50	0 ?		?	..	
Coimbra	14	20	50	10		?	..	
Paris—								
Parc St. Maur	13	41	50	1	86	51	..	
Montsouris	13	34	49	54	..		..	
Brussels	13	28	50	5	86	36		?
Greenwich	13	45	50	13	87	2	124	5 ?
Kew	13	48	50	12	87	10	124	10
Geldeston	13	39	50	2	86	59	123	31
Oxford	13	53	50	15		?	..	
Falmouth	14	4	50	25		?		?
Valencia	14	25	50	51	87	42		?
Armagh	14	15	50	45	87	22	124	30 ?
Liverpool	13	58	50	25	87	20	124	5 ?
Stonyhurst	13	55	50	27	87	0	124	10

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* Times given by Professor Ragona, Director of Royal Observatory, Modena.

† This time differs slightly from that given by Professor Cacciatore of Palermo Observatory. The time scale of the curve is very contracted.

TABLE III.—*continued.*

Station.	Passage of Wave.							
	I.		III.		V.		VII.	
	hrs.	min.	hrs.	min.	hrs.	min.	hrs.	min.
Glasgow..	14	2	50	38	87	15	124	20
Aberdeen	13	52	50	32	87	12	124	20
Toronto	17	33	55	18	92	0	127	43
New York	17	53	55	21		?		?
Hastings-on-Hudson, N.Y.	17	56 ?	55	41 ?		?		?
Washington	18	0	55	33	92	11	128	0 ?
Mexico		?		?		?		?
Havana	19	0 ?*	55	50 ?		?		?
Cordoba		?		?		?		?

* This oscillation occurred a little after 19 hours, but the time scale is too contracted to allow of the time being obtained with much exactness.

NOTE.—A ? inserted alone in the column indicates that the "Wave" cannot be identified in the trace. When a blank is inserted in the column it indicates that no trace has been received for that period.

Table IV. gives the times of the passage of the waves returning towards Krakatoa from its Antipodes. These are numbered as II., IV., and VI.

TABLE IV.

Observed times of the successive passages of the waves returning towards Krakatoa, after having passed its Antipodes; reckoned from 0 hours of August 27th, 1883, Greenwich Mean Time, civil reckoning.

Station.	Passage of Wave.					
	II.		IV.		VI.	
	hrs.	min.	hrs.	min.	hrs.	min.
Melbourne	34	25	69	40	..	
Sydney	33	55	69	25		?
Dunedin	32	0	68	0 ?		?
Wellington, N.Z.	32	15	68	0 ?		?
South Georgia	27	49	64	0 ?		?
Loanda	30	33	66	38	102	23
Mauritius	34	30	70	40	105	55
Bombay	34	23	69	33		?
Calcutta..	34	48		?		?
Zi-Ka-Wei	35	39		?	..	

TABLE IV.—*continued.*

Station.	Passage of Wave.					
	II.		IV.		VI.	
	hrs.	min.	hrs.	min.	hrs.	min.
Tokio	34	20		?		?
Pawlowsk	29	28	63	53	..	
St. Petersburg	29	24	63	49	..	
Buda-Pesth	28	20	64	10	..	
Vienna	29	9	..		..	
Berlin	28	37	63	14		?
Leipsic	28	40?		?		?
Magdeburg	28	36	63	18?	98	8?
Munich	28	30	63	40		?
Modena	28	16*	62	36*	97	31*
Rome	28	55		?		?
Palermo	29	27?†		?		?
San Fernando	27	0	62	2	..	
Lisbon	27	17	62	32	..	
Serra da Estrella	27	30?	62	0?		?
Coimbra	27	15	62	23	..	
Paris:—						
Parc St. Maur	28	21	63	4	..	
Montsouris	28	21	..		..	
Brussels	28	23	62	40?	97	53
Greenwich	27	58	62	45	98	0
Kew	28	5	62	42	98	0
Geldeston	28	6	62	44	98	4
Oxford	28	5	62	35		?
Falmouth	27	43	62	27	98	0
Valencia	27	15	62	10	97	13
Armagh	27	32	62	22	97	7
Liverpool	27	41	62	40	97	10?
Stonyhurst	27	45	62	35	97	10
Glasgow	27	45	62	26	97	8
Aberdeen	27	52	62	32	98	20
Toronto	25	48	57	53	91	18
New York	25	26	58	18		?
Hastings-on-Hudson, N.Y.	25	26?	58	16?		?
Washington	25	20	57	51	91 or 90	8 23 ?
Mexico		?		?		?
Havana	24	15?	57	0?		?
Cordoba		?		?		?

* Times given by Prof. Ragona, Director of Royal Observatory, Modena.

† This time differs slightly from that given by Prof. Cacciatore, of Palermo. The time scale of the curve is very contracted.

NOTE.—A ? inserted alone in the column indicates that the "Wave" cannot be identified in the trace. When a blank is inserted in the column, it indicates that no trace has been received for that period.

From the times thus recorded may be deduced the probable precise moment of the occurrence of the great explosion, of which there is otherwise no satisfactory or complete evidence, as well as the velocities of the wave's transmission in its course round the earth.

But, as will be more fully shown hereafter, the velocity of transmission was not uniform in all directions, nor did it remain constant as the wave advanced. In order, therefore, to determine the most probable moment of the origin of the wave, it has been considered best to deal only with the data obtained from the stations nearest to, and immediately surrounding, Krakatoa:—viz., Calcutta, Zi-Ka-Wei (Shanghai), Bombay, Melbourne, Mauritius, and Sydney; at all which the records of the first passage of the wave are well defined and satisfactorily comparable, while their distances from Krakatoa are not so great as to make it likely that important variations of the velocity of the wave took place during the time occupied in reaching them.

If T is the time of the origin of the wave, which is to be determined; t, the time of the passage of the wave at any station; d, the distance in degrees from the point of origin; and V, the velocity of the wave's transmission, assumed to be the same in all cases; then

$$\mathrm{V} = \frac{d}{t - \mathrm{T}}$$

and representing by $d_1, d_2, \ldots . d_6$, the several distances of the six stations from Krakatoa; by $t_1, t_2, \ldots . t_6$, the several observed times of passage of the wave; and by $\Sigma(d)$ and $\Sigma(t)$ the sums of the distances and times, we shall have for the most probable values of T and V.

$$\mathrm{T} = \frac{\Sigma(t).\ \Sigma(d^2) - \Sigma(d.t).\ \Sigma(d)}{6\ \Sigma(d^2) - \overline{\Sigma(d)}|^2} = 3\cdot54 \text{ hours} = 3 \text{ hrs. } 32 \text{ min. G.M.T.}$$

$$\mathrm{V} = \frac{6\ \Sigma(d^2) - \overline{\Sigma(d)}|^2}{6\ \Sigma(dt) - \Sigma\,(t).\ \Sigma\,(d)} = 10\cdot31 \text{ degrees, or } 713 \text{ English miles per hour.}$$

The residual errors of observation, assuming the above values, are shown in the following Table V.

TABLE V.

Station.	d.	t.	$t-$T.	$d\div$V.	Error in Time.	$\frac{d}{t-\mathrm{T.}}$	Error in Velocity.
	°	Hrs.	Hrs.	Hrs.	Hr.	°	°
Calcutta	33·13	6·78	3·24	3·21	−·03	10·23	−·08
Zi-Ka-Wei	40·37	7·45	3·91	3·92	+·01	10·32	+·01
Bombay	40·70	7·43	3·89	3·95	+·06	10·46	+·15
Melbourne	47·88	8·23	4·69	4·64	−·05	10·21	−·10
Mauritius	48·48	8·28	4·74	4·70	−·04	10·23	−·08
Sydney..	50·55	8·40	4·86	4·90	+·04	10·40	+·09

From which it may be concluded that the probable error of the deduced time of origin of the wave is ± ·04 hour, or about $2\frac{1}{2}$ mins.; and that of the velocity of the wave ± ·09 degree, or 6 miles per hour.

As was before observed, however, the phase of the oscillation taken as the standard, in reckoning the times of the wave's passage over the several stations, is not the initial extraordinary rise, but the lowest part of the depression following it. It is not easy to define precisely the true commencement of the disturbance which precedes the passage of the standard phase of the oscillation over the several stations, and there may be an error of at least 5 minutes in the determination that has been adopted as most probable. This, however, gives for the mean of five of the last-mentioned stations 36 minutes earlier, and all agree within 4 minutes of that value. Sydney is excluded from this determination, as the trace is too irregular to admit of a satisfactory result being obtained.

Consequently the probable moment of the great explosion was 3 hrs. 32 mins., *minus* 36 mins. = 2 hrs. 56 mins. G. M. T., or 9 hrs. 58 mins. local time.

A corroboration of the conclusion thus arrived at, is afforded by the register of the gasometer indicator at Batavia, which fortunately is available, and which in the absence of a continuous barometric record, supplies a fairly trustworthy indication of the atmospheric pressure at the time in question. Plate IX. is a slightly reduced facsimile of a portion of this register for the first half of August 27th.*

The distance of Krakatoa from Batavia being 1° 22′, the wave, with the velocity before calculated, would reach the latter place in 8 mins., so that it would have been felt there at 3 hrs. 4 mins., G. M. T., or 10 hrs. 11 mins., local time. The gasometer shows a sudden and most extraordinary increase of pressure at some time between 10 hrs. 15 mins. and 10 hrs. 20 mins. a.m., local time, agreeing as exactly with that above arrived at as could be expected from the somewhat rough character of the trace, the inertia of the recorder, and the possible error of the clock at a non-scientific establishment.

The oscillations of the gasometer indicator were very numerous and violent on the day of the great explosion, but following the maximum increase just referred to, there appears to have been a maximum reduction of pressure between 10 hrs. 40 mins. and 10 hrs. 50 mins. local time, corresponding therefore with the maximum fall shown in the barometric traces of the wave. It has not been possible to connect any other of the gasometer indicator oscillations with any available recorded barometric disturbances, and from this it must be inferred that the explosion at 2 hrs. 56 mins., G. M. T., was far more violent in its character than any of the others.

The intervals of time between the origin of the great wave and its *first* passage over the several stations, *direct from Krakatoa;* as well as the time intervals between the successive subsequent recurrences of the wave in its progress round the earth,

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* On the original the trace at about 10 hrs. 15 mins. passes beyond the limits of the diagram, and it is quite possible that the atmospheric pressure on the gasometer at that moment may have been sufficient to have caused the pencil to rise even higher than it did, had the construction of the recording apparatus allowed of its doing so. The figures on the right of the diagram give the indicated pressure on the gasometer in millimetres of water, while those on the left give the equivalent pressures in inches of mercury. It must be remembered, however, that, in order to get the absolute pressure on the gasometer, the figures must in each case be doubled.

after passing through the Antipodes and again returning through Krakatoa; together with the deduced velocities of the wave's transmission, are shown in Table VI.

TABLE VI.

Time intervals, and velocities between the origin and *first* passage of the wave, and between its successive recurrences travelling in the same direction.

The velocities are expressed in degrees of the Equator and decimals, per hour.

Station.	Between time of origin and passage I.		Between passages I. and III.		Between passages III. and V.		Between passages V. and VII.	
	Interval	Hourly rate.	Interval.	Hourly rate.	Interval.	Hourly rate.	Interval.	Hourly rate.
	hours.	degrees.	hours.	degrees.	hours.	degrees.	hours.	degrees.
Melbourne	4·70	10·19	34·97	10·29	..	..	..	..
Sydney	4·87	10·38	34·90	10·32	35·35	10·18	..	..
Dunedin	6·72	10·19	35·00	10·29	..	..	..	..
Wellington, N.Z.	6·80	10·37	35·42	10·16	..	..	..	..
South Georgia	11·87	9·38	33·00	10·91	..	..	..	..
Loanda	8·77	10·41	34·95	10·30	35·13	10·25	35·00	10·29
Mauritius	4·75	10·21	34·55	10·42	34·58	10·41	34·75	10·36
Bombay	3·90	10·44	36·57	9·84	..	..	..	..
Calcutta	3·25	10·19	36·58	9·84	..	..	..	..
Zi-Ka-Wei	3·92	10·30	35·45	10·16	..	..	..	..
Tokio	5·32	9·90	35·35	10·18	..	..	..	..
Pawlowsk	8·77	10·01	37·00	9·73	36·33	9·91	..	..
St. Petersburg	8·70	10·11	36·42	9·88	37·08	9·71	..	..
Buda-Pesth	8·97	10·27	36·42	9·88	35·83	10·05	..	..
Vienna	9·03	10·41	36·58	9·84	..	..	..	..
Berlin	9·33	10·30	36·75	9·80	36·62	9·83	36·38	9·90
Leipsic	10·47	9·23	..	..	..	..	..	..
Magdeburg	9·45	10·28	36·48	9·87	35·05	10·27	..	..
Munich	9·05	10·73	36·92	9·75	35·50	10·14	..	..
Modena	9·32	10·46	36·33	9·91	36·25	9·93	36·17	9·95
Rome	9·47	10·16	35·92	10·02	..	..	..	..
Palermo	10·08	9·46	..	..	..	..	..	..
San Fernando	9·83	11·29	35·83	10·05	..	..	..	..
Lisbon	10·75	10·50	35·92	10·02	..	..	..	..
Serra da Estrella	10·30	10·82	36·17	9·95	..	..	..	..
Coimbra	10·80	10·38	35·83	10·05	..	..	..	..
Paris:—Parc St. Maur	10·15	10·16	36·33	9·91	36·83	9·77	..	..
Montsouris	10·03	10·29	36·33	9·91	..	..	..	..
Brussels	9·93	10·24	36·62	9·83	36·52	9·86	..	..
Greenwich	10·22	10·21	36·47	9·87	36·82	9·78	37·05	9·72
Kew	10·27	10·18	36·40	9·89	36·97	9·74	37·00	9·73
Geldeston	10·12	10·20	36·38	9·90	36·95	9·74	36·53	9·85
Oxford	10·35	10·15	36·37	9·90	..	..	..	..
Falmouth	10·53	10·23	36·35	9·90	..	..	..	..
Valencia	10·88	10·15	36·43	9·88	36·85	9·77	..	..
Armagh	10·72	10·05	36·50	9·86	36·62	9·83	37·13	9·70
Liverpool	10·43	10·15	36·45	9·88	36·92	9·75	36·75	9·80
Stonyhurst	10·38	10·15	36·53	9·85	36·55	9·85	37·17	9·69
Glasgow	10·50	10·10	36·60	9·84	36·62	9·83	37·08	9·71
Aberdeen	10·33	10·12	36·67	9·82	36·67	9·82	37·13	9·70
Toronto	14·02	10·14	37·75	9·54	36·70	9·81	35·72	10·08
New York	14·35	10·13	37·47	9·61	..	..	..	..
Hastings-on-Hudson, N.Y.	14·40	10·10	37·75	9·54	..	..	..	..
Washington	14·47	10·17	37·55	9·59	36·63	9·83	35·82	10·05
Havana	15·47	10·43	36·83	9·77	..	..	..	..

The corresponding time intervals between the origin of the wave and its second passage over the several stations, after having travelled from Krakatoa through its

Antipodes; as well as the intervals between the successive subsequent passages of the wave, after travelling in the same direction round the earth, through Krakatoa, and again returning through its Antipodes ; together with the deduced velocities of the wave's motion, are shown in Table VII.

TABLE VII.

Time intervals and velocities between the origin and *second* passage of the wave, and between its successive recurrences travelling in the same direction.

The velocities are expressed in degrees of the Equator and decimals, per hour.

Station.	Between time of origin and passage II.		Between passages II. and IV.		Between passages IV. and VI.	
	Interval.	Hourly rate.	Interval.	Hourly rate.	Interval.	Hourly rate.
	Hours.	Degrees.	Hours.	Dagrees.	Hours.	Degrees.
Melbourne	30·88	10·11	35·25	10·21	..	..
Sydney	30·38	10·19	35·50	10·14	..	..
Dunedin	28·47	10·24	36·00	10·00	..	..
Wellington, N.Z.	28·72	10·08	35·75	10·07	..	..
South Georgia	24·28	10·24	36·18	9·95	..	..
Loanda	27·02	9·95	36·08	9·98	35·75	10·07
Mauritius	30·97	10·06	36·17	9·95	35·25	10·21
Bombay	30·85	10·35	35·17	10·24	..	..
Calcutta	31·27	10·45	..	..	..	..
Zi-Ka-Wei	32·12	9·95	..	..	..	..
Tokio	30·80	9·98	..	..	..	..
Pawlowsk	25·93	10·50	34·42	10·46	..	..
St. Petersburg	25·87	10·52	34·42	10·46	..	..
Buda-Pesth	24·80	10·80	35·83	10·05	..	..
Vienna	25·62	10·38	..	..	..	..
Berlin	25·08	10·52	34·62	10·40	..	..
Leipsic	25·13	10·48	..	..	..	..
Magdeburg	25·07	10·48	34·70	10·37	34·83	10·34
Munich	24·97	10·53	35·17	10·24	..	..
Modena	24·73	10·61	34·33	10·49	34·92	10·31
Rome	25·38	10·39	..	..	..	..
Palermo	25·92	10·21	..	..	..	..
San Fernando	23·47	10·61	35·03	10·28	..	..
Lisbon	23·75	10·41	35·25	10·21	..	..
Serra da Estrella	23·97	10·37	34·50	10·43	..	..
Coimbra	23·72	10·45	35·13	10·25	..	..
Paris:—Parc St. Maur	24·82	10·35	34·72	10·37	..	..
Montsouris	24·82	10·35	..	..	..	..
Brussels	24·85	10·39	34·28	10·50	35·22	10·22
Greenwich	24·43	10·47	34·78	10·35	35·25	10·21
Kew	24·55	10·41	34·62	10·40	35·30	10·20
Geldeston	24·57	10·45	34·63	10·40	35·33	10·19
Oxford	24·55	10·39	34·50	10·43	..	..
Falmouth	24·18	10·43	34·73	10·37	35·55	10·13
Valencia	23·72	10·52	34·92	10·31	35·05	10·27
Armagh	24·00	10·51	34·83	10·34	34·75	10·36
Liverpool	24·15	10·52	34·98	10·29	34·50	10·43
Stonyhurst	24·22	10·51	34·83	10·34	34·58	10·41
Glasgow	24·22	10·49	34·68	10·38	34·70	10·37
Aberdeen	24·33	10·50	34·67	10·38	35·80	10·06
Toronto	22·27	9·78	32·08	11·22	33·42	10·77
New York	21·90	9·80	32·87	10·95	..	..
Hastings-on-Hudson, N.Y.	21·90	9·80	32·83	10·97	..	..
Washington	21·80	9·76	32·52	11·07	{ 32·53 or 33·28	11·07 or 10·82
Havana	20·72	9·59	32·75	10·99	..	..

The velocities of the wave thus obtained will be seen to range from about 9°·75 per hour to 10°·5 per hour, or from 674 to 726 English miles per hour. The velocity of sound in air, of a temperature of 50° Fahrenheit, is 757 miles per hour, and at 80° Fahrenheit it is 781 miles; at a temperature of zero Fahrenheit it is reduced to 723 miles per hour. Thus it appears that the atmospheric disturbance now in question had very nearly the characteristic velocity of sound, and that its mode of propagation by an aërial oscillation, of comparatively short duration, was also closely analogous to that of sound. Moreover, although there is no direct evidence that the great final explosion, which produced this atmospheric disturbance, was accompanied by sounds heard at any considerable distance, it is well established that during the progress of the eruption the sounds of some of the explosions were heard at very great distances; certainly at Ceylon, about 2,000 English miles from the volcano, and at many places between 1,000 and 1,500 miles distant; and probably at Rodriguez, about 3,000 English miles distant. Further details on this subject will be found in the subsequent section upon *Sounds.*

The results given in Tables VI. and VII., when examined more closely, indicate that there were sensible variations in the velocity of the wave's transmission in the same direction over the various stations, and that the velocity of the waves moving in different directions over the earth's surface likewise differed considerably. Some of the apparent variation is, no doubt, due to the imperfection of the data, and the difficulty before mentioned of identifying the standard phase of the wave, on the moment of the occurrence of which such calculations as these must be based. But the differences are too great and too consistent to be entirely, or even mainly, attributed to these causes.

This will be made apparent from the following considerations. The velocity of the wave, in degrees per hour, in passing round the earth, is 360°, divided by the time of transit. If this time be assumed to be approximately 36 hours, and the variation from it, whether positive or negative, be called x, in hours, the velocity will be $\frac{360°}{36+x}=10°-y$, where y is the corresponding variation of the velocity from 10° per hour. Consequently, $y=\frac{10x}{36+x}$, and hence an error of 10 mins. in the time would produce a change in the deduced velocity of only 0°·046 per hour, and an error of half an hour would change the velocity by only 0°·137 per hour. The probable limits of error in the estimation of the times are, in almost all cases, well within thirty minutes, and the few exceptions that are found have no practical influence on the general conclusions adopted.

It will be seen that there is great general similarity in the respective time intervals and velocities for the whole series of stations, comprised in the two tables between Pawlowsk and Aberdeen, which includes all the European stations on which the most confidence can be placed. The paths of the portions of the wave that passed over these places do not vary greatly in azimuth, and, presumably, the general conditions of temperature also will not have varied greatly among them.

Now, from Table VI. it will be found that the mean velocity of the wave for twenty-nine of these stations, in passing for the first time from Krakatoa to them, is 10°·23 per hour. The average velocity in the same direction between the first and third passages, over twenty-seven of the same stations, during which the wave completed the circuit of the earth, was reduced to 9°·89 per hour ; the mean time occupied in the passage being 36 hrs. 24 mins. For the next passage round the earth the mean velocity for eighteen of the stations was 9°·86 per hour, and the time occupied 36 hrs. 30 mins. ; while, for the last observed passage over ten stations the mean velocity was 9°·77 per hour, and the period which elapsed was 36 hrs. 50 mins.

The corresponding quantities for the alternate passages of the wave, extracted from Table VII., are as follows :—The mean velocity of the wave, while travelling from Krakatoa through its Antipodes, to the same twenty-nine stations as before dealt with, is 10°·47 per hour ; for twenty-four stations the mean velocity between the second and fourth passages, during which also the circuit of the earth was completed, is 10°·35 per hour, the mean time occupied being 34 hrs. 46 mins. ; while, for the next passage, which is also the last observed in this direction, thirteen stations give a mean velocity of 10°·27 per hour, with a period of transit of 35 hrs. 4 mins.

It will further be seen that the velocities derived from the observations at Calcutta and Bombay, which lie within the zone traversed by the portion of the wave that passed over the European stations, correspond generally in character with those that have just been described, and that the reduction of the velocity between the first and third passages was almost the same.

On the other hand, at the Australian and New Zealand stations which lie within the same zone of the earth's surface, but to the eastward of Krakatoa, and over which, therefore, the movements of the several passages of the wave were in almost directly opposite directions to those over the European stations, the velocity between the first and third passages hardly differs from that between the origin and the first passage, in both which the motion of the wave was *with* the earth's rotation ; while between the origin and the second passage, as well as between the second and fourth passages, during which the wave travelled round the earth *against* the direction of rotation, the velocity is sensibly less than that observed over the European stations, where, between the same passages of the wave, its motion was in the opposite direction.

The difference of the velocities of the waves that travelled with and against the direction of the earth's rotation amounts to about four-tenths of a degree, or 28 English miles per hour, and it may probably be accounted for by the circumstance that the winds along the paths of this portion of the wave would, on the whole, have been westerly, which would have caused an increase of velocity in the wave moving with the earth's rotation, and an equal diminution in that moving in the opposite direction, so that the observed difference of 28 miles could be produced by an average westerly current of 14 miles per hour, which is not unlikely.

There is some appearance of a greater retardation of the wave in passing in a direction opposed to the earth's rotation over the northern European stations as compared with those in the south of Europe, which may possibly be due to the lower temperature of the more northern part of the zone traversed. This difference is not to be traced in the wave moving in the opposite direction, which may be accounted for by the path of the wave, when approaching Europe from the west, having lain for a long distance over the Atlantic, where the differences of temperature between the northern and the southern borders of the zone traversed would have been relatively small.

The velocities observed at Mauritius and Loanda, the paths of the waves passing over which lie respectively within 20° and 10° of the Equator, are very nearly alike; the wave travelling to the west not being sensibly retarded, while that travelling to the east is so retarded. This may be caused by the paths of the waves falling entirely within the zone of the Trade Winds, which both north and south of the Equator blow from the east, and would therefore cause a relative retardation of the wave travelling with the earth's rotation.

The path of the wave that passed over the Canadian and United States stations, and Havana, lies nearly on the meridian drawn through Krakatoa, and must have crossed both the polar circles very near the poles. The velocities obtained from these stations are peculiar. The direct wave from Krakatoa, which travelled nearly due north and close to the north pole, and its repetitions after passing round the earth in the same direction, had nearly the same velocities as those observed at the European stations, with an apparent decided retardation in the intervals between the first and third passages, and (but to a less extent) between the third and fifth. The wave that passed through the Antipodes before reaching the North American stations went nearly due south, close to the south pole; and its velocity on this its first partial passage round the earth was very decidedly reduced; but in its next complete circuit, that between the second and fourth passages over the stations of North America, the velocity appears to have been much increased, almost reaching the full rate of the true sound-wave. It is difficult to account for this, but the fact seems to be indisputable.

The peculiarities affecting the velocity of the waves will be subsequently again referred to; and diagrams are given which show graphically the manner of their occurrence, and supply further evidence of the truth of the conclusions that have now been stated.

The variations of velocity in the waves moving in opposite directions are clearly shown by the following Table VIII., which gives the time intervals between the passage of the successive waves, irrespective of their direction. When the time intervals increase, either the first, third, and fifth passages are accelerated, or the second, fourth, and sixth are retarded; and when the intervals diminish, the converse holds good.

TABLE VIII.

Time intervals between the passages of the successive waves, irrespective of their direction.

Station.	Interval between Passages.											
	I.–II.		II.–III.		III–IV.		IV.–V.		V.–VI.		VI.–VII.	
	hr.	min.	hr.	min.	hr.	min.	hr.	min.	hr.	min.	hr.	min.
Pawlowsk	17	10	19	50	14	35	21	45				
St. Petersburg	17	10	19	15	15	10	21	55				
Aberdeen	14	0	22	40	12	0	24	40	11	8	26	0
Glasgow	13	43	22	53	11	48	24	49	9	53	27	12
Armagh	13	17	23	13	11	37	25	0	9	45	27	23
Stonyhurst	13	50	22	42	12	8	24	25	10	10	27	0
Liverpool	13	43	22	44	12	15	24	40	9	50	26	55
Berlin	15	45	21	0	13	37	23	0				
Geldeston	14	27	21	56	12	42	24	15	11	5	25	27
Magdeburg	15	37	20	52	13	50	21	13	13	37		
Valencia	12	50	23	36	11	19	25	32	9	31		
Oxford	14	12	22	10	12	20						
Greenwich	14	13	22	15	12	32	24	17	10	58	26	5
Kew	14	17	22	7	12	30	24	28	10	50	26	10
Leipsic	14	40										
Brussels	14	55	21	42	12	35	23	56	11	17		
Falmouth	13	39	22	42	12	2						
Paris—												
Parc St. Maur	14	40	21	40	13	3	23	47				
Montsouris	14	47	21	33								
Vienna	16	35	20	0								
Munich	15	55	21	0	14	10	21	20				
Buda-Pesth	15	50	20	35	15	15	20	35				
Modena	15	25	20	55	13	25	22	50	12	5	24	5
Rome	15	55	20	0								
Serra da Estrella	13	40	22	30	12	0						
Coimbra	12	55	22	55	12	13						
Lisbon	13	0	22	55	12	20						
Palermo	15	50										
San Fernando	13	38	22	12	12	50						
Mean	14	41	21	46	12	51	23	28	10	51	26	15
Calcutta	28	1	8	34								
Bombay	26	57	9	37	25	33						
Mean	27	29	9	6	25	33						

TABLE VIII.—*continued.*

Station.	Interval between Passages.					
	I.-II.	II.-III.	III.-IV.	IV.-V.	V.-VI.	VI.-VII.
	hr. min.	hr. min.	hr. min.	hr. min.	hr. min.	hr. min.
Mauritius	26 13	8 20	27 50	6 45	28 30	6 15
Loanda	18 15	16 42	19 23	15 45	20 0	15 0
Mean	22 14	12 31	23 37	11 15	24 15	10 38
Dunedin	21 45	13 15	22 45			
Wellington, N.Z.	21 55	13 30	22 15			
Mean	21 50	13 23	22 30			
Melbourne	26 11	8 47	26 28			
Sydney	25 31	9 23	26 7	9 14		
Mean	25 51	9 5	26 18	9 14		
South Georgia	12 25	20 35	15 36			
Tokio	25 29	9 52				
Zi-Ka-Wei	28 12	7 15				
Mean	26 51	8 34				
Toronto	8 15	29 30	2 35	34 7	*0 42	36 25
New York	7 33	29 55	2 57			
Hastings-on-Hudson, N.Y.	7 30	30 15	2 35			
Washington	7 20	30 13	2 18	34 20	*1 3 or 1 48	36 52 or 37 37
Mean	7 40	29 58	2 36	34 14	0 53 or 1 15	36 39 or 37 1
Havana	5 15	31 35	1 10			

* The order of the waves had been reversed here, so that the sixth wave arrived before the fifth.

From a comparison of twenty-four European stations, it appears that the mean interval between the second and first passages is greater than that between the fourth and third passages by 2 hours; and, similarly, for twelve stations the mean of the first of these intervals is greater, by 3 hrs. 40 mins., than the mean interval between the sixth and fifth passages. At two of the American stations, Toronto and Washington, the mean interval between the first two passages of the wave exceeded that between the second pair by 5 hrs. 22 mins., and the first of these intervals exceeded that between the smaller mean of the third pair of passages by 8 hrs. 41 mins. The result of this great variation in the velocity of the waves was that at last the two waves from the opposite directions became confused, and must have crossed each other; and some doubt therefore exists as to the precise time that should be assigned to their respective passages.

In order to illustrate the manner in which the disturbance travelled round the earth, a series of projections, Plates X., XI., XII., and XIII., have been prepared, on which the position of the wave is marked for each successive even hour of Greenwich mean time, beginning with 4 hrs. of August 27th, civil reckoning, till its traces were lost. The projection or development, which is quite conventional, shows Krakatoa and its Antipodes in the centres of two circles, representing the two hemispheres, of which those points are the poles. The geographical features of the earth are projected on the hypothesis that distances from the centres of the two circles are the distances of the points to be represented, measured over the earth's surface on the arc of a great circle, from Krakatoa or from its Antipodes, as the case may be. The diameters of the circles represent great circles passing through Krakatoa, and therefore indicate the paths of the various points of the wave as it advanced.

The wave of atmospheric disturbance, if it had been propagated without interference, would have spread outwards from Krakatoa, in a gradually expanding small circle, until it reached a distance of 90° from its origin, and thus have formed a great circle; beyond which it would have contracted as it advanced, till it once more coalesced into a point or focus at the Antipodes. Thence it would return in like manner, and again be concentrated at its starting point; and so on, until it gradually died out.

The departure of the curved lines (which represent the successive positions of the wave) from a true circular form, indicates the irregularity in the velocity of the various points of the wave's front, and the distortion naturally increases gradually with the prolonged duration of the wave's progress.

The phenomena are otherwise represented in Plates XIV. and XV., which show more clearly the variation of the velocities of the wave's movement over the several stations, and contrast the velocities of the motion in directions which may be spoken of, in general terms, as being in conformity with, or in opposition to, that of the earth's rotation.

In these two plates the time-intervals are represented by the ordinates, or vertical distances from the base line, which corresponds with the assumed origin of the reckoning, viz., 0 hrs. of August 27th, G.M.T., civil reckoning. The distances of the several stations from Krakatoa, as measured on arcs of great circles, are the abscissæ or horizontal distances from the central line, supposed to represent the origin of the wave; those on the right of the central line, Plate XV., being the distances measured to the westward, or against the earth's rotation; those on the left,

Plate XIV., being the distances measured in the opposite direction. An addition of 360° is made for each complete passage of the wave round the earth.

The inclined lines drawn through the point where the central line cuts the assumed moment of the origin of the wave, and the points on the proper ordinates which represent the time of passage of the wave at the several stations, indicate the velocity of the wave's transmission; an increased inclination showing reduced velocity, and the converse. To distinguish between the waves that passed over different places, the lines of velocity are differently drawn, as is explained on the Plate itself.

The retardation of that portion of the wave which travelled by way of the South Pole to the North American stations, already referred to on page 74, is very well shown by the diagram, Plate XIV., illustrating the progress of the wave travelling *with* the earth's rotation. The line drawn from Krakatoa to Toronto has at first a greater inclination than any other line, indicating that the velocity of the wave was, in this part of its course, the least of all; but afterwards the inclination becomes less than that of any other line, showing that the velocity of the wave had changed and become the greatest of all.

The observations at South Georgia, which, speaking in a general manner, lies in the same track, confirm those at the American stations; and indeed it seems that the greatest retardation took place in the Southern Ocean, since (as the diagram will show), the inclination of the velocity line would have had to be still further increased to make it pass exactly through the point representing South Georgia.

Probably an explanation of this peculiar feature of the phenomena may be found in the conditions of the wind and weather in the Southern Ocean, during the days on which the wave passed over it, which are not known to us.

SECTION II.—SOUNDS.

In Table IX., p. 80, will be found a list of places at which the sounds of the explosions were heard; and although the list is not a complete one, it is as nearly so as it was possible to make it with the information available. The repetition, however, of places comparatively close to the Strait of Sunda could have given but little additional value to the list, which, as it stands, contains all the more distant places at which it has been reported that the sounds were heard.

No sounds were heard before the 26th; and all the reports agree that the most violent detonations occurred on the morning of the 27th. Owing, however, to the great uncertainty which is attached to the times at which it is stated that the sounds were heard—from the somewhat general way in which they are sometimes given, *e.g.*, "at *about* 10 a.m.," or "*between* 9 and 10 a.m.," &c., the unreliability of the clocks, or from other causes—the exact times at which the explosions occurred cannot safely be deduced from them ; although, as far as they bear upon the conclusions already deduced from other sources as to the time of origin of the great air-wave, so far from their being opposed to those conclusions they appear to support them fairly well.

The sounds were heard with great distinctness over the most distant parts of Java and Sumatra throughout the morning of the 27th, but it is very remarkable that at many places in the more immediate neighbourhood of the volcano they ceased to be heard soon after 10 a.m., although it is known that the explosions continued with great intensity for some time longer. Very probably this peculiar phenomenon was caused by the large amount of solid matter which at about that time (10 a.m. local time) was ejected into the atmosphere by the volcano, and which formed in the lower strata of the air a screen of sufficient density to prevent the sound waves from penetrating to those places over which it was more immediately suspended.

The principal places mentioned in the Table have been marked upon Plate XVI., which is a map constructed upon a projection similar to that used for showing the progress of the air-wave, and having Krakatoa as its centre.

Small circles have been drawn upon this map with radii of 10°, 20°. . . . 50° ; and it will be seen that the 30° line is touched, or closely approached, by places almost entirely surrounding Krakatoa ; viz., Ceylon to the north-west, Perth and other stations in West and South Australia to the south-east, New Guinea to the east, and Manila to the north-east. Diego Garcia, in the Chagos Group, almost due west of Krakatoa, and Alice Springs, in South Australia, are beyond the 30° line ; while Rodriguez, to the south-west of Krakatoa, still more remote, lies beyond the 40° line. The shaded portion of the map represents approximately the area over which the sounds of the explosions were heard, and is roughly equal to rather less than one-thirteenth of the entire surface of the globe.

A special interest is attached to the report from Rodriguez, owing to the fact that it is not only the most remote place at which the sounds of the explosions were heard, being very nearly 3,000 English miles from Krakatoa, but that it is also the only instance on record of sounds having been heard at anything like so great a distance from the place of their origin. It may, therefore, be well to quote here the account given by Mr. James WALLIS, Chief Officer of Police, who is responsible for the following narration :—

"On Sunday the 26th the weather was stormy, with heavy rain and squalls ; the wind was from S.E., blowing with a force of from 7 to 10, Beaufort scale. Several times during the night (26th—27th) reports were heard coming from the eastward, like the distant roars of heavy guns. These reports continued at intervals of between three and four hours, until 3 p.m. on the 27th, and the last two were heard in the directions of Oyster Bay and Port Mathurie."

At Diego Garcia, upwards of 2,250 English miles from Krakatoa, the sounds were very distinctly heard, and were supposed to be those of guns fired by a vessel in distress ; a belief which likewise prevailed at Port Blair in the Andaman Islands, and at several places less remote from Krakatoa. In Ceylon, and also in Australia, the sounds were heard at many different places far removed from each other ; while at Dorey, in New Guinea, they were clearly heard, and their occurrence was recorded at the time, long before it was known to what cause they were due. These circumstances are of value as confirmatory evidence of the sounds having been really heard at those distant places.

That the detonations were heard so much further to the westward than they appear to have been to the eastward of Krakatoa, was most probably due to the westward motion of the lower strata of the atmosphere in the region of the Trades, within which the most distant station, Rodriguez, lies.

It may be noticed also that a communication was made to the "Académie des Sciences," and published in the *Comptes Rendus* in March, 1885 (vol. c., p. 755), giving an account of sounds said to have been heard in the Cayman Islands in Lat. 20° N. Long. 80° W. from Greenwich, South of Cuba, on August 26th, 1883, which were attributed to the eruption at Krakatoa. The evidence, however, is of so indefinite a nature that it has not been inserted in the tabular statement annexed.

TABLE IX.

List of Places at which the SOUNDS of the Explosions at Krakatoa were heard on the 26th and 27th of August, 1883.

PLACE.	Distance from Krakatoa, in English miles.	NOTES.
JAVA.		
Anjer	31	The sounds of the explosions were heard from the afternoon of the 26th.
Merak	38	"At 7 p.m. 26th, heavy detonations and violent shocks, but no earthquake."
St. Nicholas Point	44	Sounds heard on 26th and 27th.
Chikandie Udik..	62	"The reports grew louder and louder, until the ground shook sensibly. When evening set in (26th), the detonations, far from diminishing, increased in violence." Report by an English resident.
Batavia	94	"On 26th, about 4 p.m., a series of detonations was heard; towards night they grew louder; till in the early morning the reports and concussions were simply deafening." Report by Lloyd's agent at Batavia.

TABLE IX.—*continued.*

PLACE.	Distance from Krakatoa, in English miles.	NOTES.
Serang	48	The loudest sounds were heard shortly after 10 a.m. on the 27th.
Buitenzorg	100	A low rumbling sound heard at 1 p.m., 26th, increasing in intensity soon afterwards, and continuing all through the night, with occasional violent explosions.
Samarang	346	Sounds were heard from the evening of the 26th till the afternoon of the 27th.
Carimon Java Island	355	Under the belief that a vessel was in distress, several native boats were despatched to render assistance on the evening of the 26th.
Near Toelong Agong, 100 miles from Sourabaya.	About 400 (?)	"The noise sounded like great guns being fired at irregular intervals, and it continued all through the night, 26th–27th." Extract from letter of Mr. Edward St. George.
Sourabaya (also on board the *Sea Witch*, ashore in the bay).	507	The detonations were heard on the 26th and 27th so distinctly that it appeared impossible they could have come from such a distance as Krakatoa.
Probolingo	542	The sounds were heard on the 26th and 27th.
Banjoe Wangi, Straits of Bali	616	The sounds were heard on the 26th and 27th.
Yugya Karta	357	
SUMATRA.		
Telok Betong	44	The loudest report was at about 10 a.m., 27th.
Katimbang, north-east coast of Sunda Strait.	24	"When it had become quite dark on the 26th, fearful detonations were heard, like thunder and reports of guns." The loudest report was heard at about 10 a.m. on 27th.
Palembang	228	The aërial vibrations were so strong as to cause the walls of houses to shake. The sounds were heard from the afternoon of the 26th till the morning of the 27th.
Siak	519	The sounds were heard from the afternoon of the 26th till 11 a.m. 27th.
Deli	818	The sounds were heard on the 26th and 27th.
Acheen	1,073	It was supposed that a fort was being attacked, and, in consequence, the troops were put under arms.
Kotta Radja	931	The sounds were not heard after the night of the 26th–27th.
Padang	512	"At 8.30 a.m., 27th, a heavy explosion, repeated five minutes afterwards. . . . . During all this time a fearful noise was heard from afar, which became stronger after 11 a.m." The sounds were first heard at 5 p.m. 26th.
Bencoolen	277	The sounds were heard from the afternoon of the 26th.
Kroë	134	The sounds were heard on the 26th and 27th. A report was heard on the morning of the 28th also.

TABLE IX.—*continued.*

PLACE.	Distance from Krakatoa, in English miles.	NOTES.
BANCA.		
Minto	284	The detonations were most violent during the night of the 26th.
Lepa Island	242	The loudest reports were heard near mid-day on the 27th. It was thought that a vessel was in distress.
BILLITON.		
Tanjong Pandang	277 (about)	Loudest shortly before noon on the 27th.
STRAITS SETTLEMENTS.		
Singapore	522	Two steamers were sent on the 27th to look for the vessel which was supposed to be firing guns as signals of distress. "Till 3 p.m. on Monday, the 27th, conversation was utterly impossible on the Ishore telephone line. On raising the tubes a perfect roar, as of a waterfall, was heard, and by shouting at the top of one's voice the clerk at the other end heard the voice, but not one single sentence was understood. The same noise, but to a less extent, was noticed on every line here, and sometimes, while listening to the Ishore line instruments, a report like a pistol was heard." (The telephone line crosses the strait between Singapore and Ishore by a short cable about one mile in length.)
Selangore	715	The sounds were heard from 4.30 p.m. 26th till 5 p.m. 27th.
Perak	770	The sounds were thought to be distant salvos of artillery. Reports were heard on the 26th and 27th.
Penang	868	At 11 a.m. 27th the sounds were mistaken for a salute from an American corvette, which, however, had sailed four hours previously.
SIAM.		
Bangkok..	1,413	The reports were heard on the 27th, and are also said to have been heard 100 miles in the interior.
COCHIN CHINA.		
Cape St. James, 10° 19′ N., 107° 6′ E.	1,138	The sounds were heard on the 27th.
Saigon	1,164	The sounds were heard on the 27th

TABLE IX.—*continued.*

PLACE.	Distance from Krakatoa, in English miles.	NOTES.
BORNEO.		
Martapoera	684	First heard on 26th.
Bandjermasin	666	First heard on the 26th.
Jampaga	583	The sounds were heard on the 27th.
Soekadana	461	The sounds were heard on the 26th and 27th.
Pontianak	493	First heard at 7 p.m. 26th; loudest at 11 a.m. 27th.
Labuan	1,037	The sounds appear to have been heard only on the 27th.
Banguey Island	1,235	See also the note, page 88, by Commander Hon. F. Vereker, R.N., H.M.S. *Magpie.*
Elopura	1,210	"It seemed as if heavy guns were being fired, at a distance of not over four or five miles away" (27th).
St. Lucia Bay	1,116	"The noise of the eruption was plainly heard all over Borneo. The natives inland, who murdered poor Witti, when they heard the noise, thought we were coming to attack them from the east and west coasts, and bolted away from their village" (26th–27th). Letter of L. von Donop, North Borneo.
Samarinda, Koetei	911	The sounds were heard on the 26th and 27th.
PHILIPPINE ISLANDS.		
Palawan	1,450 (about)	"The detonations were heard on the 27th, half-way up the Palawan coast."
Manila, Luzon	1,804	The sounds were imagined to be signals from a ship in distress, and preparations were made to render assistance (27th).
CELEBES.		
Manado, 1° 30′ N., 124° 47′ E..	1,435	The sounds are said to have been heard not only in the town, but over the entire province in which it is situated (from the evening of the 26th to the 27th).
Macassar..	969	Two steamers were sent to sea on the 27th to ascertain the cause of the reports. The sounds were heard over the whole province.
Island of Lombock	790	The reports were heard in all parts of the island, as well as in the adjoining one of Bali (26th–27th).
Island of Timor..	1,351	The sounds were heard all over the island. A Government steamer was despatched to ascertain their cause (26th–27th).

Table IX.—*continued.*

Place.	Distance from Krakatoa, in English miles.	Notes.
NEW GUINEA.		
Salwatty Island, North-west coast.	1,800	"The Rajah of Salwatty, whom I met at the village of Samatu, told me that the noise of the eruption had been audible there." Dr. F. H. Guillemard, M.A., F.L.S. (No date given.)
Dorey, Geelvink Bay .. .	2,014	"The reports were heard on the 27th by M. van Hasselt, residing at Dorey, and recorded at the time in his diary. The natives reported to him that they had heard similar sounds on the 26th. He described the sounds as being like distant cannonading." Extract from letter of Dr. F. H. Guillemard, M.A., F.L.S.
WEST AUSTRALIA.		
Perth	1,902	"This coast has been visited (27th) by . . . . sounds as of the firing of guns inland." Staff-Commander Coghlan, R.N.
Geraldton	1,675	At Geraldton and at Cossack the meteorological observers reported that sounds were heard on the 27th resembling heavy guns, the reports at Geraldton being preceded by a rumbling noise. The observer at Cossack says that similar reports were heard along the coast from the Ashburton to the Sherlock rivers, and inland as far as the Hammersley range.
Cossack	1,286	
Victoria Plains	1,700 (about)	"People were startled by hearing a series of loud reports, resembling those of artillery at a distance in a north-westerly direction. The first sounds were heard by a few persons at 11 p.m. on Sunday (26th), continuing at irregular intervals till about 4 p.m. on Monday; sometimes as many as three reports occurred in a minute, but generally there was a few minutes' interval." *Western Australian*, September 4.
SOUTH AUSTRALIA.		
Alice Springs, 23° 41′ S., 133° 37′ E.	2,233	"Two distinct reports, similar to the discharge of a rifle, were heard on the morning of the 27th, and similar sounds were heard at a sheep camp nine miles west of the station, and also at Undoolga, 25 miles east." Report by Mr. Skinner.
Undoolga, 25 miles east of Alice Springs.	2,250 (about)	
Daly Waters, 16° 18′ S., 133° 25′ E.	2,023	"On Sunday, the 26th, at midnight we were awakened by an explosion resembling the blasting of a rock, which lasted for a few minutes. Next morning, between 9.30 and 10 o'clock, a similar noise, with slight vibration, was heard and felt, continuing for 15 minutes. Men camped five miles south of Daly Waters also heard it, and the noise was heard also at Elsey Creek and other places on the overland telegraph." Report by Mr. Kemp.
Elsey Creek, 15° 10′ S., 133° 23′ E.	2,003	

TABLE IX.—*continued.*

PLACE.	Distance from Krakatoa, in English miles.	NOTES.
BURMAH.		
Mergui	1,366	The sounds were heard on the 26th and 27th.
Tavoy	1,478	"All day on August the 27th unusual sounds were heard, resembling the boom of guns. Thinking there might be a wreck or a ship in distress, the Tavoy Superintendent sent out the police launch, but they could see nothing."
NICOBAR ISLANDS.	1,299	"Extraordinary sounds were heard, as of guns firing" (26th–27th). Extract from report by officer in charge.
ANDAMAN ISLANDS.		
Port Blair	1,500	"At 9.30 p.m. on the 26th a report was heard as of a distant signal gun. Steamer was sent round the coast to search for the vessel supposed to be firing as signals of distress. Similar sounds were heard at irregular intervals during the two following days." Extract from letter of Mr. E. H. Man. "Several reports were heard in Port Blair, supposed to be from some ship in distress. Weather between August the 27th and 29th very unsettled, and heavy rain and wind prevailed." Extract from Port Officer's report.
CEYLON.		
Dutch Bay	2,058	The sounds were heard from 7 a.m. to 10 a.m., 27th.
Hambantota	1,866	"Reports heard by three persons from 7 a.m. on the 26th, and by many persons during the 26th, on the night of the 26th–27th, and during the 27th. The usual style was a steady sequence of reports, and then a rapid succession of them, ending, very often, in a loud burst of two or three, or half a dozen, almost together, which was generally followed by a lull. The intensity of the sounds varied greatly."—Letter from Mr. H. Parker.
Tissa Mahâ Râma (near Hambantota).	1,870 (about)	
North Namona Koolie, Badulla.	1,904	Heard at noon on the 27th, and continued for half an hour. "I thought it might be some volcano in action out at sea, or else ships firing heavy guns."
Tumpalancholai and Mahâ Oya (on the Badulla road).	1,893	"Captain Walker and Mr. Fielder were puzzled at various times during the forenoon of the 27th, by hearing noises as if blasting was going on, though there was nothing of the sort for a very considerable distance, if anywhere in the district."

TABLE IX.—*continued.*

PLACE.	Distance from Krakatoa, in English miles.	NOTES.
Mulliyavalai	1,996	"The District Mudaliyar reported that sounds were heard, as if cannon were being fired, from midnight, August 26th, till noon, August 27th. The sounds seemed to come from the east, and from no great distance. The apparent proximity of the explosions reported from the Mulliyavalai Pattu may have been due to the hilly nature of the country there." Report by Mr. S. Haughton, Assistant Government Agent.
Rambodde	1,888	Sounds, resembling distant guns, were heard.
Madulsima	1,902	At first the sounds were thought to be those of guns fired at Trincomalee. First heard on the 26th.
Batticaloa	1,888	"At about midnight, 26th, I heard about five or six times a noise as of a cannon, at intervals of 15 minutes, towards the east. On the morning of the 27th, too, about three times I noticed a noise similar to that of the discharge of a cannon over the sea towards the east." From Signaller's report. "The Sub-Collector states that at about 6 p.m. on the evening of the 26th he heard a loud report, as if a cannon was discharged down southward, which he and the people near him thought to be thunder." Report by Mr. Elliott, Acting Government Agent.
Kalmunai	1,877	"Mr. Christie, of the Public Works Department, told me he had heard loud explosions seawards that morning (27th), and that, as they seemed like the discharge of heavy artillery, he presumed some man-of-war was practising with her big guns out of sight of land, as he could see no ships." Report by Mr. Elliott.
Kokkulai	1,980	Sounds as of firing of cannon at Trincomalee.
Chemmalai	1,980	
Kotinalie Valley	1,928	The sounds were heard on the 27th.
Bogawantalawa	1,911	"The sounds were heard here most distinctly. They were like blasting on the Billhulloya side, and kept on all day, from 7.30 a.m. till 4 p.m." (27th).
Galle	1,932	The sounds were heard on the 27th.
Mannâr	2,047	"Loud sounds, resembling the report of distant cannon, were heard to the eastward on the 27th." Report by Mr. Fowler, Assistant Government Agent.

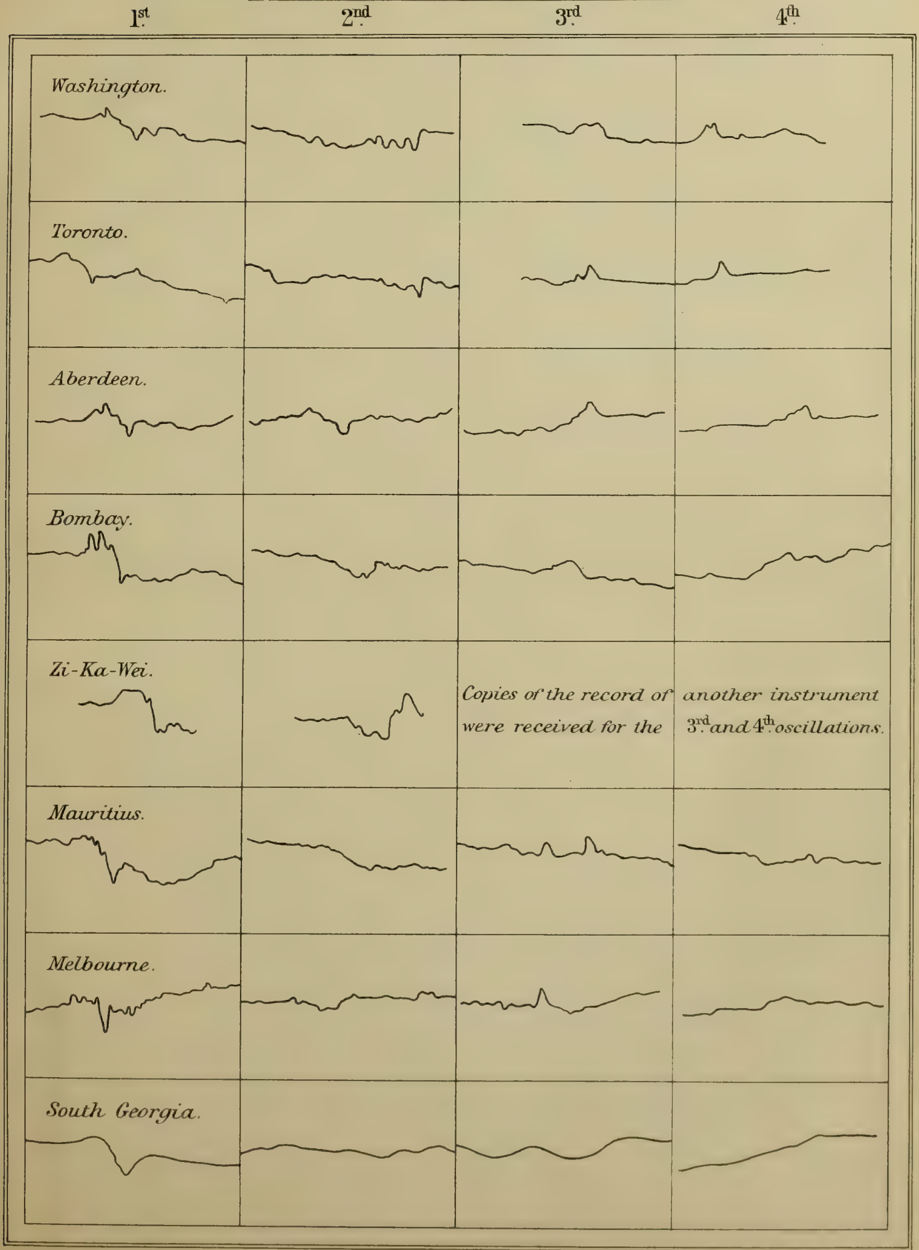
TABLE IX.—*continued.*

PLACE.	Distance from Krakatoa, in English miles.	NOTES.
Kotaimunai	1,900 (about)	"I heard distinctly, at about 6 p.m. on the 26th (local time), a loud report, as if a cannon was discharged down southward." Report by Mr. Alfred Koch.
Lunugala	1,889	Like heavy guns fired at sea in the direction of Hambantota on the 27th.
CHAGOS ISLANDS.		
Diego Garcia	2,267	"Le lundi 27 Août entre 10 et 11 heures du matin, pendant le déjeûner, nous avons entendu des détonations sourdes mais violentes. Nous avons cru tellement à l'appel d'un navire en détresse que nous avons couru et que j'ai envoyé plusieurs hommes vers le rivage extérieur de l'île sur plusieurs points différentes, en observation. Le Capitaine Florentin, de *l'Eva Joshua*, et son second M. Daniel Sauvage, venaient de quitter Pointe de l'est pour aller mouiller à Pointe Marianne, lorsqu'ils ont entendu les mêmes détonations. Ils ont aussitôt envoyé des hommes en observation à l'extrémité des mâts. Mais comme les miens ils n'ont rien vu." Extract from letter of M. Lecomte.
RODRIGUEZ.	2,968	"Several times during the night of the 26th–27th reports were heard coming from the eastward, like the distant roars of heavy guns. These reports continued at intervals of between three and four hours, until 3 p.m. on the 27th (= 5·48 p.m. local time at Krakatoa), and the last two were heard in the direction of Oyster Bay and Port Mathurie." Report by Mr. James Wallis, Chief of Police.
VESSELS AT SEA.		
Barque *Wm. H. Besse*—Off Northern portion of Java.	From about 40 to 20 east of Krakatoa. Vessel approaching the volcano.	"Throughout the afternoon and night of the 26th we heard heavy reports, like the discharge of heavy artillery. At 10 a.m. on the 27th we heard some terrific reports."
Ship *Charles Bal*	From about 11 south to 67 N.E. of Krakatoa.	"The sounds were very intense, and continuous from 3.30 p.m., 26th, to 1.30 p.m., 27th.
Ship *Borjild*	About 75 east of Krakatoa.	At anchor near Great Kombuis Island throughout the 27th.
SS. *Anerley*—From the Strait of Banca to near the North Watcher Island.	From about 250 to 90 N.E. of Krakatoa.	"Noise on the 27th resembled distant cannonading." "The detonations were heard all over the Island of Banca during the 26th–27th."
Ship (? name)—Off Lepa Island.	About 230 N.N.E. of Krakatoa.	The sounds were first heard on the 26th.

TABLE IX.—*continued.*

PLACE.	Distance from Krakatoa, in English miles.	NOTES.
Brig *Airlie*—Lat. 0° 30′ S., Lon. 105° 54′ E.	390	"At 3 p.m. 26th. Sounds like those of heavy artillery, which continued till about 10 p.m. The last report made the ship tremble all over."
Ship *Ida*—Lat. 2° 42′ N., Lon. 108° 12′ E.	622	The sounds were heard on the 27th to the south-south-eastward.
H.M.S. *Magpie*—Lat. 5° 52′ N., Lon. 118° 22′ E.	1,227	"The noise of the detonations caused by Mount Krakatoa, resembling distant heavy cannonading, was distinctly heard by us, and by the inhabitants of this coast as far as Banguey Island, on August 27th." Commander Hon. Foley C. P. Vereker, R.N.
Barque *Charlotte*—From Lat. 11° 42′ S. and Lon. 107° 54′ E., to Lat. 8° 18′ S. and Lon. 106° 42′ E.	414 to 166	The sounds of the explosions were heard from 5 p.m. 26th till 10 a.m. 27th.
Brigantine *Adriatic*—Lat. 10° S., Lon. 105° E.	265	The sounds of the explosions were heard on the 26th and 27th.
Barque *Jonc*—Lat. 4° 46′ S., Lon. 90° E., to Lat. 7° 45′ S., Lon. 93° E.	1,072 to 865	Sounds were heard on the 26th and 27th.
Brig *Catherine*—Lat. 6° 31′ S., Lon. 86° 46′ E., to Lat. 9° S., Lon. 87° 19′ E.	1,291 to 1,268	The sounds were first heard on the evening of the 26th.
Brig *Brani*—Lat. 1° 39′ S., Lon. 92° 17′ E., to Lat. 2° 59′ S., Lon. 92° 11′ E.	944 (mean)	"Constant peals of thunder were heard on the 26th and 27th in the direction of Sumatra, but without any appearance of lightning."
Ship *Lennox Castle*—Lat. 0° 0′, Lon. 91° 23′ E.	1,060	The sounds were heard on the 26th.
Ship *Barbarossa*—Lat. 1° 42′ S., Lon. 93° 12′ E., to Lat. 2° 36′ S., Lon. 92° 54′ E.	900	Sounds heard on the 27th in south-east like guns or distant thunder, but no lightning visible.

ENLARGED COPIES OF BAROGRAMS FROM EIGHT SELECTED STATIONS SHOWING THE CHARACTER OF THE FIRST FOUR OSCILLATIONS.

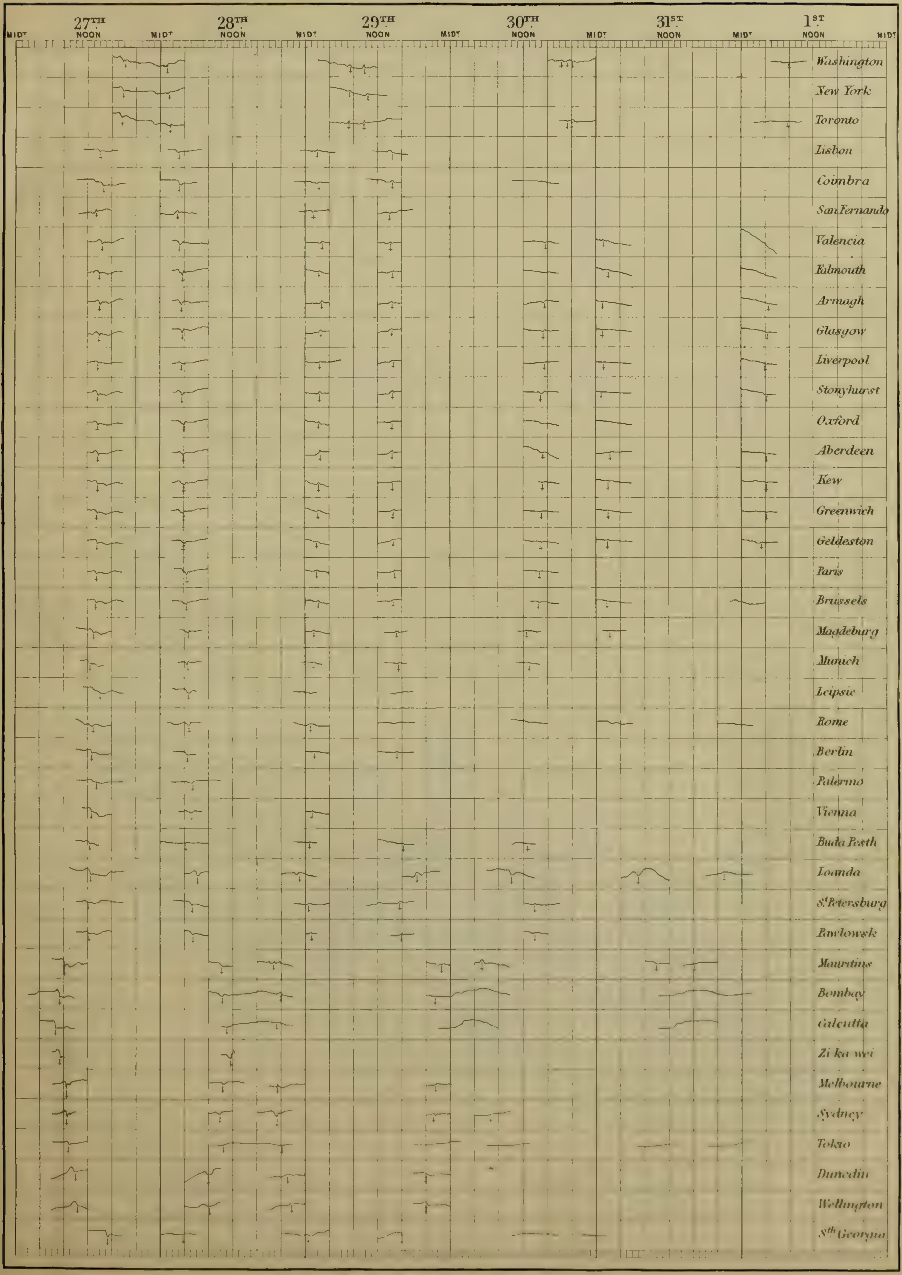


Copies of the record of another instrument were received for the 3rd and 4th oscillations.

[illegible] & [illegible] lith.

BAROMETER CURVES

AUGT. & SEPTR. 1883.

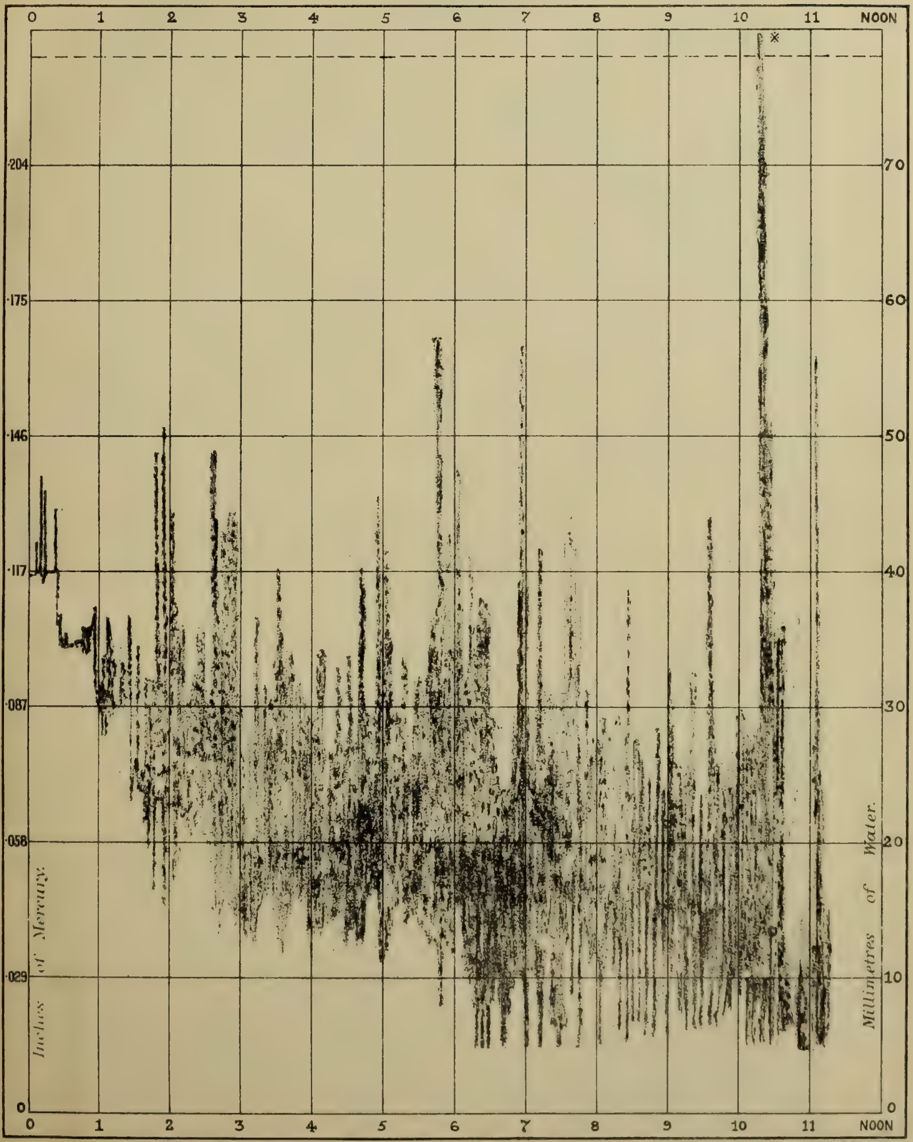


The Mark ↓ indicates the part of the trace selected for Measurement

REDUCED COPY OF A PORTION OF THE RECORD OF PRESSURE ON THE

BATAVIA GASOMETER

27TH AUGUST, 1883.



Maltby & Sons, Lith

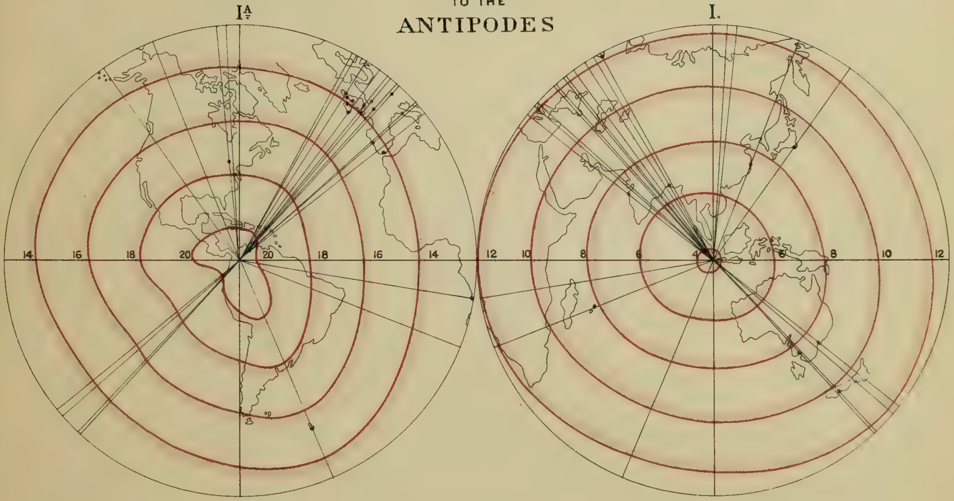
———— = 1 Hour.
———————— = 10mm. } Original Scales.

※ See note in text p. 73

The Scale on the original diagram terminates at the point marked with a dotted line.

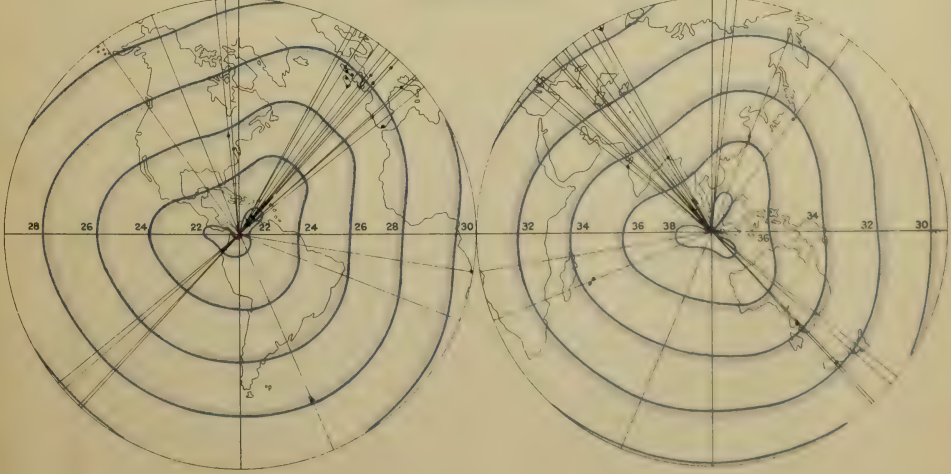
WAVE Nº I.

FIRST PASSAGE FROM
KRAKATOA
TO THE
ANTIPODES



WAVE Nº II.

FIRST PASSAGE FROM
ANTIPODES
BACK TO
KRAKATOA



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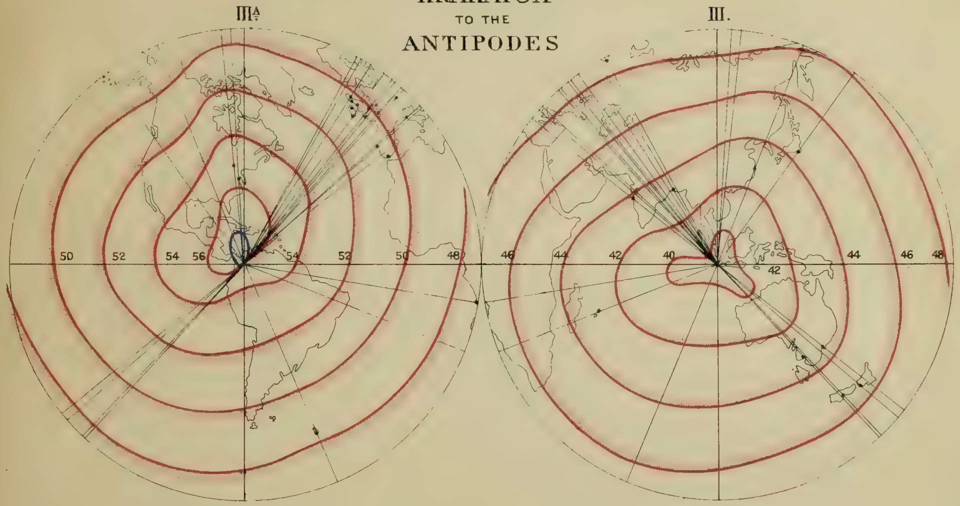
WAVE Nº III.

SECOND PASSAGE FROM

KRAKATOA

TO THE

ANTIPODES



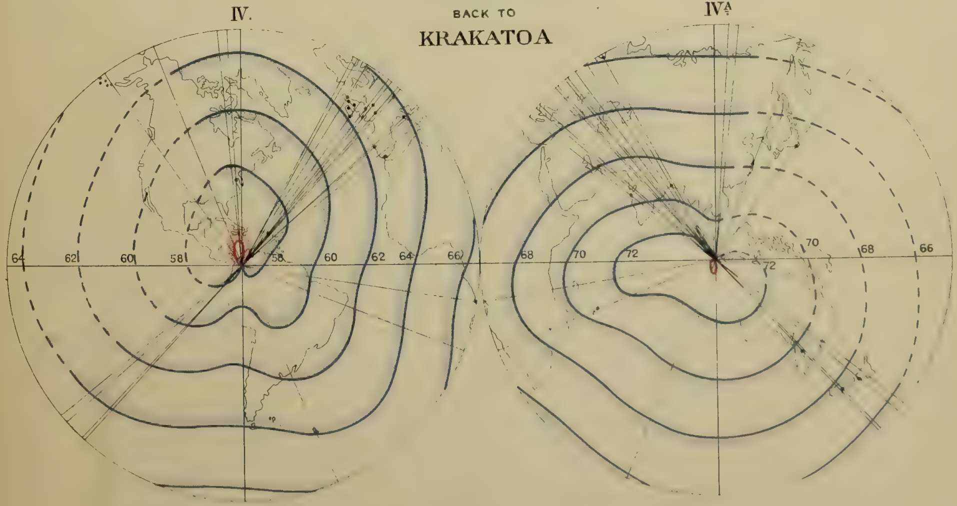
WAVE Nº IV.

SECOND PASSAGE FROM

ANTIPODES

BACK TO

KRAKATOA



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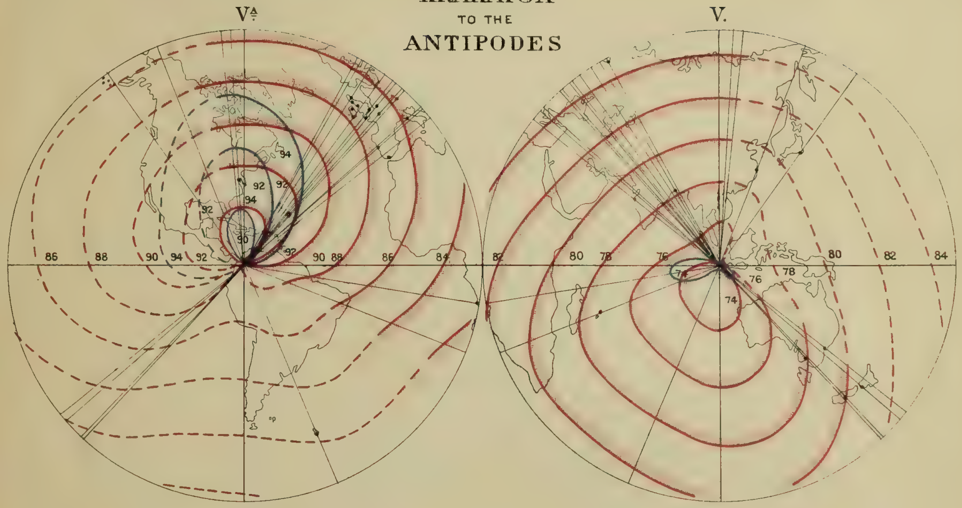
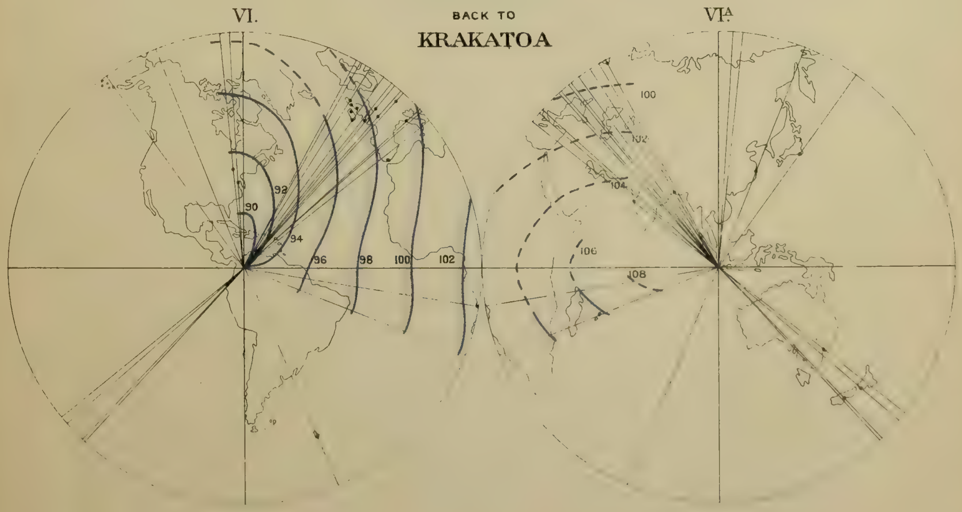
WAVE Nº V.

THIRD PASSAGE FROM
KRAKATOA
TO THE
ANTIPODES



WAVE Nº VI.

THIRD PASSAGE FROM
ANTIPODES
BACK TO
KRAKATOA



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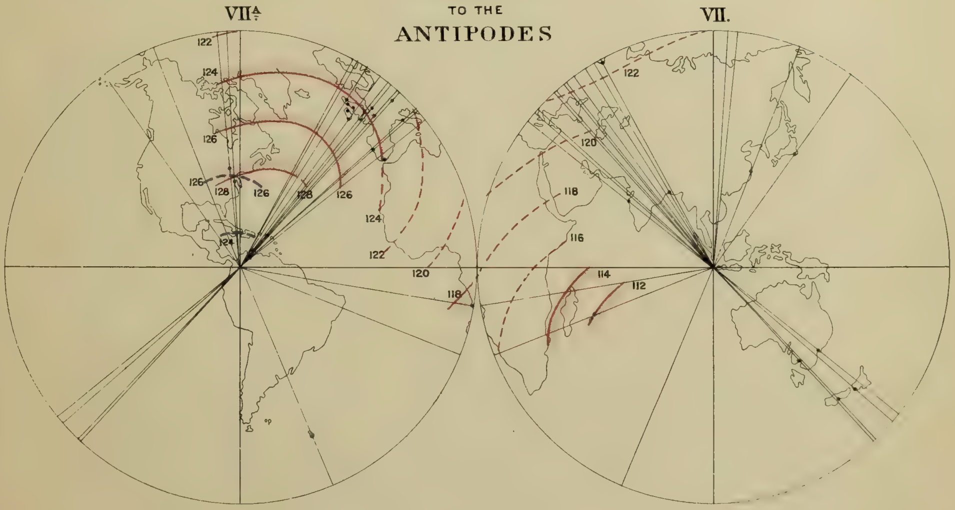
WAVE No. VII.

FOURTH PASSAGE FROM

KRAKATOA

TO THE

ANTIPODES



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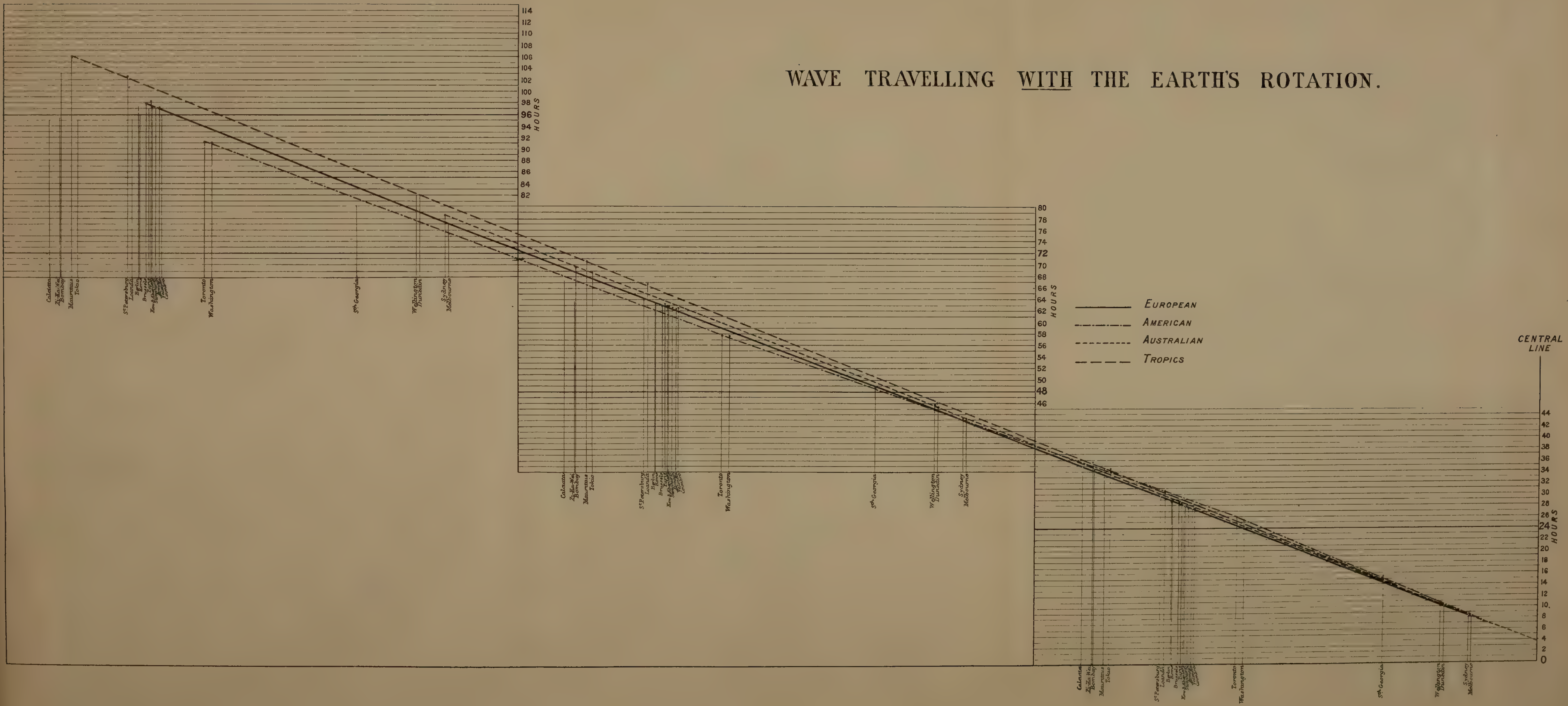
WAVE TRAVELLING WITH THE EARTH'S ROTATION.



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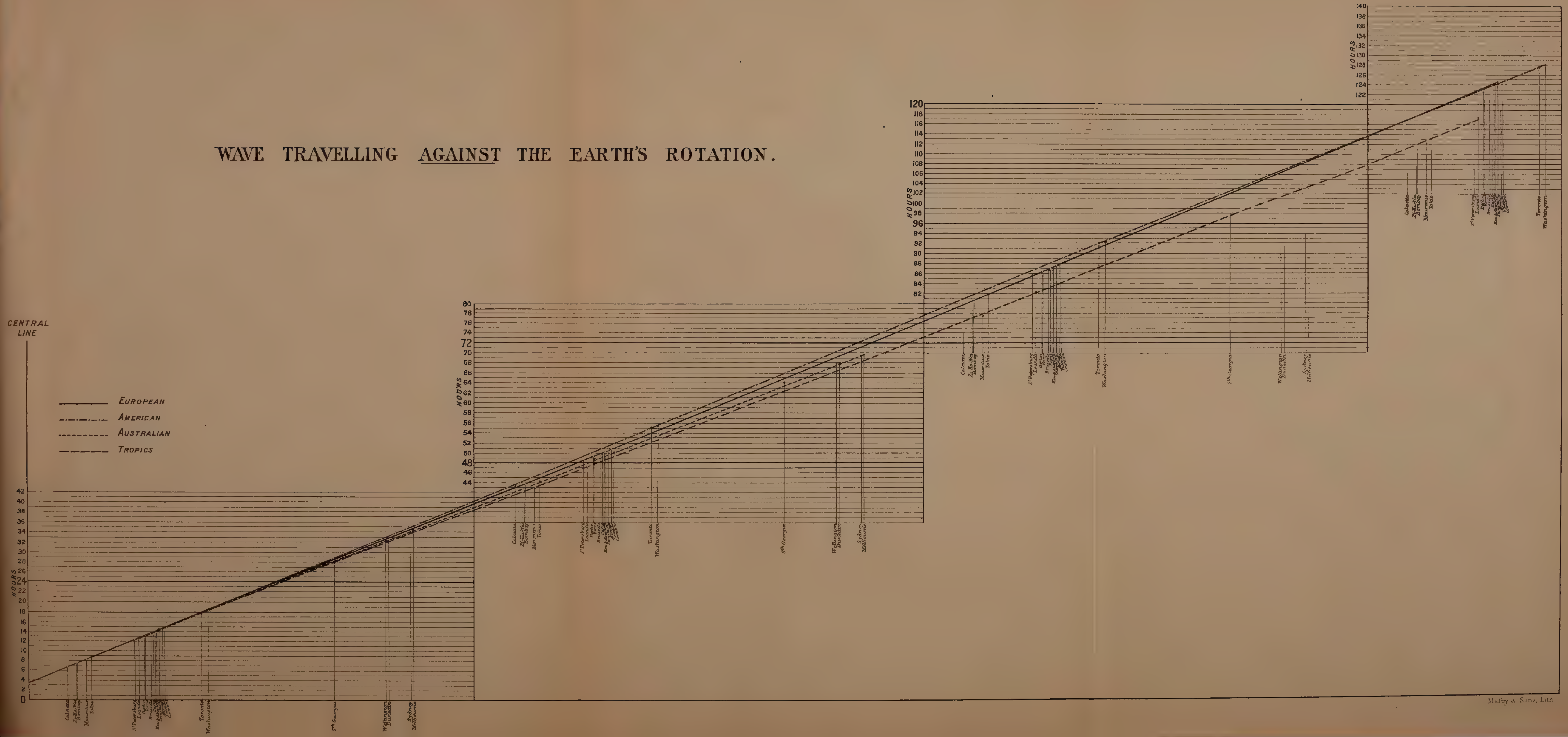
WAVE TRAVELLING AGAINST THE EARTH'S ROTATION.



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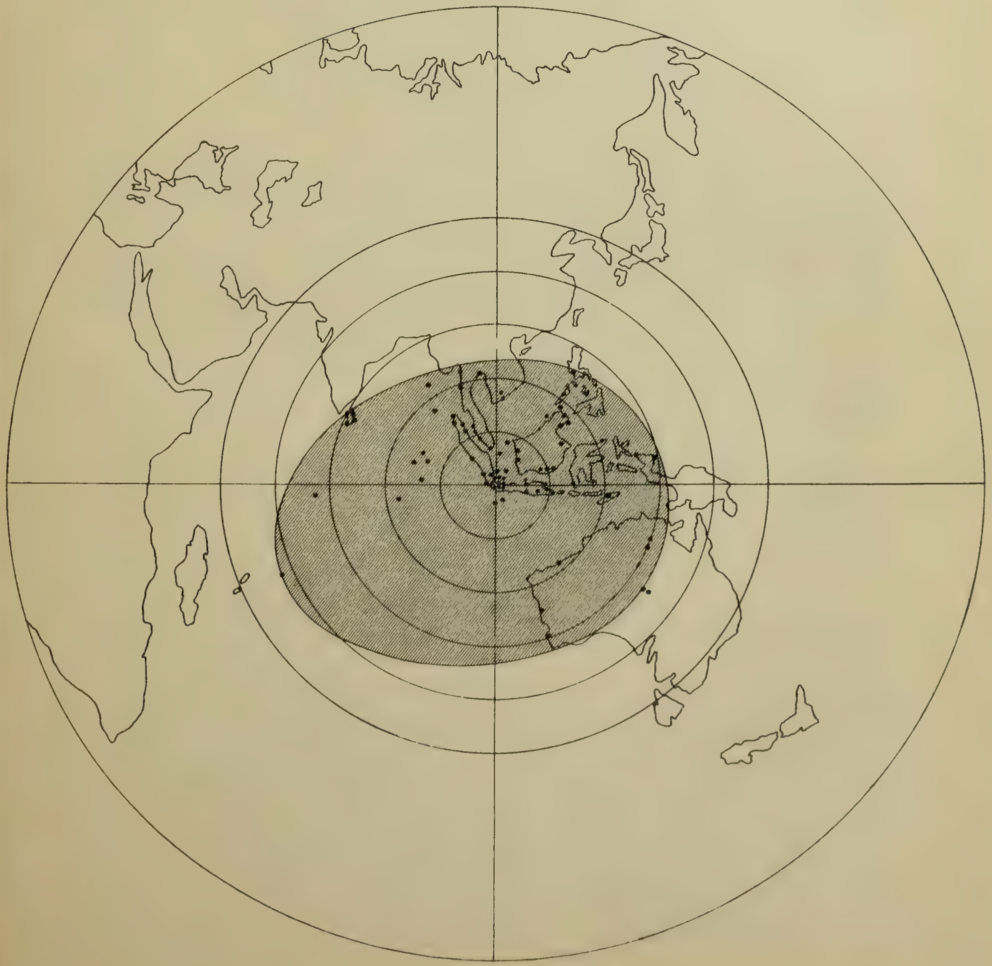
MAP SHOWING THE PLACES AT WHICH THE SOUNDS OF THE EXPLOSIONS WERE HEARD ON AUGUST 26-27

THE SHADED PORTION INDICATES APPROXIMATELY THE AREA OVER WHICH THE SOUNDS WERE HEARD.



PART III.

ON THE SEISMIC SEA WAVES CAUSED BY THE ERUPTION OF KRAKATOA, AUGUST 26TH AND 27TH, 1883.

By Captain W. J. L. Wharton, *R.N., F.R.S., in completion of the unfinished Notes of Captain Sir* F. J. Evans, *R.N., K.C.B., F.R.S.*

[In this Part Geographical miles alone are used.]

On the lamented death of Sir Frederick Evans, an examination of the papers connected with the sea disturbance consequent upon the eruption of Krakatoa, on which he was at work, revealed a number of notes showing that he had made considerable advance with their discussion. I was requested to look at these unfinished notes; and at first I came to the conclusion that a small amount of labour would suffice to complete them. When, however, I took upon myself to do this, I soon found that I had miscalculated the task, and that the notes left, though very clear, were but the preliminary foundation of the report; and, moreover, that it would be impossible to carry it on where Sir F. Evans had left off, as many points presented themselves which required a thorough examination of the mass of original matter.

Sir F. Evans had commenced to form a table of the speed of the waves, and his notes related principally to the selection of the crests marked on the different diagrams as those identical with the first arrival of the great wave from Krakatoa. These I have verified, and in nearly every case have come to the same conclusion as Sir F. Evans.

For the text of the report and the deductions which I have made I alone am responsible, as no clue was left as to any opinion Sir F. Evans may have formed on the different points raised.

The time used throughout is civil mean time in days of 24 hours, counting from midnight. In the text, local time is referred to. For the calculation of the periods of translation of the waves, the time is reduced to Greenwich civil time, but this is given only in the tables showing the net results of the investigation.

Account of the Phenomena relating to Sea Disturbance in the immediate vicinity of Krakatoa.

Mr. R. D. M. Verbeek, a Dutch mining engineer resident at Buitenzorg, a town situated in the interior of Java, about 30 miles south of Batavia, has collected all the evidence forthcoming of the details of the eruption of Krakatoa which commenced on May the 20th, 1883, and culminated on August the 27th. This he has published in his work "*Krakatau*," Parts I. and II., which, accompanied by charts and sketches, forms a complete history of the outbreak and its effects in the immediate vicinity.

As this is accessible, a comparatively brief statement of the leading proven or accepted facts in connection with the great sea disturbance in the immediate neighbourhood of the eruption will probably suffice as an introduction to the consideration of the question of its propagation to distant shores. (*See* also Part I.)

During the earlier eruption in May, and up to August, no remarkable movement of the water was observed. The violence of the explosions recommenced during the early afternoon of the 26th of August, a particularly heavy detonation being heard at about 17.30 on that day.

This was marked by the pressure gauge of the gas works at Batavia at about the same time; and, between 18 and 19 hours, the first large wave reached the Java shore at Tyringin, 24 miles from Krakatoa, where it destroyed many houses near the sea. At about the same time a wave caused considerable damage at Telok Betong, at the head of Lampong Bay in Sumatra, 44 English miles from Krakatoa.

At about 19 hrs., or 19 hrs. 30 mins., the low-lying Chinese Camp at Merak was swept away. At Anjer this wave was only about 5 feet high.

From this time the sea in the Strait of Sunda was much agitated, but no further large wave is recorded until the morning of the 27th.

On the 27th at 1 hr. the village of Sirik, 6 miles south of Anjer, was submerged; and one account mentions a wave at Telok Betong at 1 hr. 30 mins.

At about 6 hrs. 30 mins. a wave swept away nearly the whole of Anjer, which lay low, and this was followed at about 7 hrs. 30 mins. by another, which completed the destruction. At the same time the lower part of Telok Betong, in Sumatra, was overwhelmed. Two heavy air waves are recorded on the gas pressure gauge at Batavia at 5 hrs. 43 mins. and 6 hrs. 57 mins., which are probably connected with the explosions causing these waves.

At some time after 10 o'clock an immense wave inundated the whole of the foreshores of Java and Sumatra, bordering the Strait of Sunda, and carried away the remaining portions of the towns of Tyringin, Merak, and Telok Betong, as well as many other hamlets and villages near the shore.

To this wave, undoubtedly the largest, must be attributed the disturbance which spread so far over the surface of the ocean.

At places comparatively near and immediately exposed to the direct disturbance emanating from Krakatoa, no mention is made of waves after this great one, nor is even the great wave itself recorded. The darkness, and the fact of all the survivors of the 6 hrs. 30 mins. and 7 hrs. 30 mins. waves having fled from the shore, are sufficient to account for this omission. At the lighthouse at Vlakke Hoek alone, the great wave is said to have repeated itself three times at intervals of about half-an-hour.

At one or two places outside the Strait the waves were observed to continue. Thus at Tjabang, about 90 miles to the north, in Sumatra, eleven waves were counted between 15 hours on the 27th and 6 hours on the 28th. At Batavia, the disturbance lasted from noon on the 27th to midnight on the 28th ; and fourteen waves, with a steady period, were marked on the tide gauge. As the explosions of the volcano continued during the whole of the 27th, it may fairly be assumed that some other waves were generated subsequent to the 10 o'clock one.

After 16 hrs. 30 mins. the detonations are mentioned as gradually diminishing in force until 6 hours on the 28th.

Several ships were in the Strait during the great eruption and experienced terrible weather, heavy squalls from different directions, confused sea, lightning, and a rain of mud, ashes, and pumice. None of these ships mention any particularly large waves, nor was any damage done by the sea. One vessel at anchor six miles from St. Nicholas Point, mentioned a rapid current of 10 knots an hour (estimated) running towards the volcano some time after the great explosion.

It is specially worthy of remark that no earthquake shock is recorded at any time during the eruption, except on the evening of the 26th, when, at Anjer, the earth is said to have trembled.

When the site of the eruption could be examined, it appeared that the following changes had taken place :—

Of the north part of the island of Krakatoa, an area of nearly six miles, with an average height of 700 feet, had disappeared, on which the sea rolled of a depth not yet ascertained, but over 150 fathoms in some places. Taking the average height of the missing portion to be 700 feet, and the present depth at 300 feet, the mass of matter thus blown away may be considered as $1\frac{1}{8}$ cubic miles.

The portion of the island that remained seems to have received, according to Mr. VERBEEK, an addition of about one square mile, by upheaval on the side remote from the portion which disappeared. This cannot be considered very certain, seeing that the former survey by Mr. J. RICHARDS, R.N., did not pretend to be accurate, as the original in the Hydrographic Department shows.

The Peak, 2,647 feet high (Richards's Survey), had been shorn in two, leaving on the north face of the remaining portion a precipitous cliff of the same height

Verlaten Island, which lay close to the north-west of Krakatoa, had a superficies of about one square mile before the eruption. It now has an area of nearly three miles.

Lang Island, to the north-east, and also close to Krakatoa, was little changed, but had received a slight addition on its northern side.

Two small new islands of mud and pumice, almost a-wash, standing on extensive banks, had made their appearance seven miles to the northward of Krakatoa, where formerly a depth of 80 feet existed.

The depths over an area of 140 square miles around Krakatoa had undergone alterations; in most cases upheaval having taken place, but in some, subsidence. The precise amount is difficult to estimate, as the old soundings were in many parts scanty, but the general fact of change may be taken for granted.

Beyond this area, no alteration has yet been discovered in the depth of the sea, so that the movement is assumed to have been comparatively local. The first reports, to the effect that the whole of the Strait of Sunda had been altered, were exaggerations.

In one part the change is very marked, and materials exist for more detailed statements. Between Lang Island and Sebesi, over an area of about 72 square miles, the depths are greatly reduced. The bank, 18 miles in area, on which the two new islands, Steers and Calmeyer, stood, has now an average depth of 12 feet, where formerly it had 120 feet. Over the remainder of this area, or about 59 square miles, the reduction in depth averages about 30 feet. The Charts, Nos. 1 and 2, show the condition of the Strait before and after the eruption.

The times of arrival of the waves at different places on the shores of the Strait are but vaguely noted, and this is especially the case with the great wave after 10 o'clock of the 27th. Terror and dismay reigned everywhere, and darkness had settled over the land. At Anjer, also, where this wave must have come, no one was left to see it, the few survivors having fled to the hills.

To some extent the same uncertainty attaches to the height of the waves. All who observed the wave after 10 o'clock, however, agree that it was the largest, and this is supported by all the evidence forthcoming. As this wave alone appears to have travelled to places at great distances, it is the most important. All observations founded on measurements of the marks left by the water are considered as relating to this wave.

The inundated portions of the shores of the Strait of Sunda are indicated on map, p. 17, and Mr. VERBEEK also mentions, in his account of the disaster, the maximum height in different localities. It is not, however, stated by whom the contours on Mr. VERBEEK's maps were obtained, nor is the means of obtaining the limit reached by the water stated in every case. As far as can be gathered, the following were the altitudes to which the wave attained at places on each shore of the Strait of Sunda, and in the immediate vicinity of the volcano.

Java Shore.

At Merak, 33 miles from Krakatoa, the height of the wave was estimated by Mr. McColl to be 135 feet; by Mr. Nieuwenhuys, an engineer, 100 feet. It does not appear on what these estimates are based. The greatest height measured at which buildings were washed away was 47 feet. Mr. Verbeek, on his plan, shows the hill sides to have been washed by the water to a height of 115 feet. The peculiar position of Merak, standing at the head of a funnel-shaped strait formed by the island of Merak, may have caused the wave to be higher there than elsewhere.

At Anjer, 26 miles from Krakatoa, the height of the wave at 6 hrs. 30 mins. is stated to have been over 33 feet. The subsequent and higher waves are not appraised.

At Tyringin, 24 miles from the volcano, 50 feet is mentioned as the measured height of the water at one spot. As people who gained the hills at the back of the plain, stated to be 67 to 100 feet high, were saved, it does not appear that the wave could have been much over 70 feet.

At Princes Island, 25 miles distant, the water is said to have attained a height of 50 feet.

Sumatra Shore.

At Katimbang, 19 miles from Krakatoa, the wave is stated by Mr. Verbeek to have reached a mean height of 80 feet.

At Telok Betong, the water reached within 6 feet of the top of the hill on which the Residence stands at a height of 78 feet, and was consequently 72 feet high. This seems the most accurate measurement of all those given. The man-of-war, "*Berouw*," was carried 1·8 miles inland up the valley, and left about 30 feet above the level of the sea.

At the lighthouse on Vlakke Hoek the water rose 50 feet.

From these different measurements I have assumed that the actual height of the wave, before it reached the shore, was about 50 feet.

To ascertain the time of the genesis of the great wave is not, at first sight, easy, nor can it by any means be arrived at with certainty.

How the wave was formed, whether by large pieces of the mass of the island falling into the sea; by a sudden submarine explosion; by the violent movement of the crust of the earth under the water; or by the sudden rush of water into the cavity of the volcano when the side was blown out—must ever remain, to a great extent, uncertain; but more of this hereafter. What precisely took place during this tremendous outburst no one knows. The island was shrouded in smoke and fire, and was never clearly seen; nor did any vessel approach near enough to note any changes in its outline during the eruption. It is, however, evident that the three larger waves were intimately connected with the three great explosions, for, though the testimony of ear-witnesses is not clear on the point of the comparative force of the different detonations, as measured by the sound, happily the pressure gauge at the gasworks at Batavia, before mentioned, gives no uncertain evidence.

This has already been referred to also in Part II., p. 69, and the record is reproduced in Plate IX., whence it will be seen that the three largest movements, viz., those at 5 hrs. 43 mins., 6 hrs. 57 mins., and 10 hrs. 18 mins., were all apparently connected with the highest three waves recorded. As far as that at 10 hrs. 18 mins. is concerned, there is reason to believe that the sea and air waves were formed practically synchronously.

Batavia is distant 83 miles in a straight line from Krakatoa. Thus, deducting 8 minutes for the time taken by the air wave to travel this distance, and 5½ minutes for the difference of longitude, the time of genesis of the air wave would be 10 hrs 4½ mins. of Krakatoa time.*

The tide gauge at Batavia also affords valuable evidence and an independent means of arriving at a time for the starting of the great wave. This automatic instrument has recorded the first great wave at 36 minutes past noon. The time taken, according to the formula, $V=\sqrt{gh}$, by a wave in travelling the distance between the two places (100 sea miles), and in the depths shown by the excellent chart which exists, is 2 hrs. 30 mins. Deducting this and the 5½ minutes' difference of longitude, we get 10 hrs. 0 min., Krakatoa time, as the hour at which the great wave left the island. This I have adopted, and I find that Mr. VERBEEK has come to the same conclusion.

On account of the intricacy of the route, this result can be considered approximate only, but the agreement with the other determination is sufficiently near to corroborate the substantial accuracy of the time assumed.

In calculating the time of the propagation of the wave to Batavia, Mr. VERBEEK has estimated the height of the volcanic wave in various sections, and calculated his speed for those sections, by the formula, $V=\sqrt{\frac{g}{2h}(h+\epsilon)(2h+\epsilon)}$, where g is gravity, h the depth of water, and ϵ the height of the crest above the normal level of the water. I have contented myself with the formula, $V=\sqrt{gh}$. My result for the time of propagation agrees exactly with that of Mr. VERBEEK, which is to be accounted for by the different routes which we have assumed the wave to take, among the numerous islands and shoals, and also by the different depths which we have calculated for the various sections; for, though I have styled the chart excellent, the bottom is so uneven that any attempt to arrive at a very accurate estimate of mean depths can be only deceptive.

To Anjer the wave would have taken 37 minutes, to Tyringin 30 minutes, to Merak 45 minutes, and to Telok Betong 61 minutes.

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* See p. 69, where General STRACHEY, from the discussion of several barograph diagrams, arrives at a slightly different conclusion.

Assuming that waves were generated at some or all of the great explosions registered by the pressure gauge at the gasworks at Batavia, the following table shows the time of arrival of such waves at the above places on the shores of the Strait of Sunda. The second column gives the measure of the force of the air waves as registered by the pressure gauge :—

Air wave at Batavia.			Water wave left Krakatoa.	Arrive at Tyringin.	Arrive at Anjer.	Arrive at Merak.	Arrive at Telok Betong.
Time.	Excess of Indicator reading above estimated normal.	Barometric equivalent.					
h. m.	mm.	in.	h. m.	h. m.	h. m.	h. m.	h. m.
26th—17 20	13	·08	17 07	17 37	17 44	17 52	18 08
27th— 1 55	20	·12	1 42	2 12	2 19	2 27	2 43
„ 2 38	21	·12	2 25	2 55	3 02	3 10	3 26
„ 4 56	22	·13	4 43	5 13	5 20	5 28	5 44
„ 5 43	41	·24	5 30	6 00	6 07	6 15	6 31
„ 6 57	41	·24	6 44	7 14	7 21	7 29	7 45
„ 9 42	29	·17	9 29	9 59	10 06	10 14	10 30
„ 10 15	63	·37	10 02	10 32	10 39	10 47	11 02
„ 11 05	40	·23	10 52	11 22	11 29	11 37	11 53

We have, however, records only of certain sea waves, which may be connected with some of the air waves.

Thus—

Air wave at Batavia.	Sea wave at	At
h. m.		
26th—17 20 p.m.	Tyringin.	Between 18 and 19.
	Telok Betong.	„ „
	Merak.	19 or 19.30.
27th— 1 55 a.m.	Sirik.	"About" 1.
„ 5 43 „	Anjer.	„ 6.30.
	Telok Betong.	Between 6 and 7.
„ 6 57 „	Anjer.	"About" 7.30.

One fact in connection with these inundations on the coasts exposed to the direct waves from Krakatoa is worthy of notice; and that is, that the earlier waves, though of no insignificant height, were partial. Thus, the wave between 18 hrs. and 19 hrs. of the evening of the 26th was scarcely noticed at Anjer, although on the same shore, to the north and south, considerable damage was done. The village of Sirik, only 6 miles from Anjer, was destroyed at 1 hr. on the 27th; but this wave is not mentioned at any other place.

Krakatoa stands in the centre of the Strait of Sunda, the shores of which form a rough elongated semi-ellipse. The outward, or western, portion of the ellipse being absent, permits free outlet for waves in that direction into the Indian Ocean. The eastern smaller end of the ellipse also is missing; and permits waves to travel in that direction through a passage 12 miles in width.

To the west, the water is clear and deepens regularly to the Indian Ocean; as far as the imperfect nature of the survey admits of estimation.

To the east, the water is comparatively shallow: a large island blocks the already narrow channel, reducing it to 9½ miles, which opens into the still shallower Java Sea, encumbered with reefs and shoals, and hemmed around by the far extending islands of the Eastern Archipelago.

To the west, therefore, the waves from Krakatoa, which we have seen were probably 50 feet in height on leaving the island, have freely spread. To the east, friction among the shoals has rapidly reduced them; so that their extension in that direction has been comparatively small.

The indications of the tide gauge of the harbour of Tanjong Priok at Batavia are most valuable, as giving the nearest and most unmistakable record of the Krakatoa waves. A glance at the diagram will show the character of the disturbance.

From 20 hrs. of the 26th, the curve begins to show signs of oscillations of level, which are, however, small until noon of the 27th, not averaging more than 3 inches. Notwithstanding, waves may be traced corresponding to the explosions of 1 hr. 42 mins., 2 hrs. 25 mins., and 5 hrs. 30 mins. of the 27th, of which the best marked is that corresponding to the 5 hrs. 30 mins. explosion, which arrived at Batavia at 8 hrs. 20 mins.

At 11 hrs. 30 mins. the water began quickly to rise; and at 12 hrs. 15 mins. a perpendicular line shows that the final rise was almost a wall of water, as the first great wave arrived and inundated the shore. This attained a height of 7½ feet above water level at the time, at 12 hrs. 36 mins. It then fell as rapidly to 10 feet below the level. These measurements are those given by Mr. VERBEEK, who states that the gauge would not register the full range of the wave. The diagram shows only + 1·60 m., and − 0·23 m., but Mr. VERBEEK states that the measurement for high level was taken on the stones of the pier as + 2·35 m.

That for low level he gives as − 3·15 m. The gauge would register − 1·10 m.; but Mr. VERBEEK gives as his explanation of the lower minimum which he adopts, that the water had already begun to rise under the influence of the second wave, before the level could fall below − 0·23 m. It is not easy to understand, if this was so, how the water could have been noted at − 3·15 m., and the shape of the curve does not give any justification for the assumption. He does not say how the observations for the minimum were taken, beyond the statement that they were made to fixed points in the port. This figure therefore for the minimum appears doubtful, and I am inclined to think that the range of this first wave cannot be considered as very exact, and is probably under the amount given by Mr. VERBEEK, which is 18 feet.

The second wave also was above the highest point the gauge would mark, and may be taken as Mr. VERBEEK gives it, 1·95 m. This wave attained its maximum at

14 hrs. 48 mins., or 2 hrs. 12 mins. after the first. Its crest was therefore 80 miles distant when the first wave arrived.

It is to be remarked that at Batavia the first phenomenon was a *rise* unpreceded by any fall of level, which appears to indicate that the wave leaving Krakatoa was a positive one.

The first wave is followed by waves of gradually diminishing height, 14 of which are at tolerably regular intervals, and give a mean period of 2 hrs. 02 mins. from crest to crest. These are :—

	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.
Times ..	12 36		14 48		16 43		18 58		20 25		22 20		0 40	
Intervals ..		2 12		1 55		2 15		1 27		1 55		2 20		2 30
Height in feet *	6¼		4½		1¾		1½		⅙		1½		1	

	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.
Times ..	3 10		5 10		7 20		9 10		11 00		13 10		14 55		17 05
Intervals ..		2 00		2 10		1 50		1 50		2 10		1 45		2 10	
Height in inches	9		11		9		4		4		2		3		3

This period of 2 hrs. 02 mins. is very remarkable if the circumstances are considered. If the wave was caused by any sudden displacement of the water, as by the falling of large masses of ejected matter, and huge fragments of the missing portions of Krakatoa, or by the violent rush of steam from a submarine vent through the water, it is hardly to be conceived that two hours would elapse before the following wave, the second of the series, started after it.

If the supposition that the wave was caused by the opening of a great chasm in the earth, by the bursting of the sides of the hollowed Krakatoa, into which the sea rushed, could be maintained, a wave of long period might also be explained ; but, though some such inrush must have occurred when the water flowed over the site of the island, to set up a long wave, as is now required, two things appear necessary :

First,—that the chasm was large enough to permit water to flow into it continuously for an hour at a rate sufficiently rapid to cause a great lowering of the water level in the vicinity of the island, in order to set up a wave.

Secondly,—that the first effect reaching the shore was a negative wave.

Now, the first supposition is so improbable that it certainly requires evidence before it can be adopted ; and the second is contrary to the record of the Batavia gauge, which shows a distinct positive wave as the earliest phenomenon.

If, however, upheaval of the bottom of the sea, more or less gradual, and lasting

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* These heights are, as all others of waves in this Part, measured from the normal level of the water at the time, as deduced from the tidal diagrams.

for about an hour, took place, we should have a steady long wave flowing away from the upheaved area, which as it approached the shore would be piled up considerably above its normal height. Thus these waves of long period would be set up; and this would also account for the rapid current recorded by the ship "*William H. Besse*," which is described as 10 miles an hour, though probably that is an exaggeration. The water would flow back on the motion ceasing.

If we now turn to the condition of the area round Krakatoa and compare it with the previous state of things, we find that, as summarized at page 92, upheaval has taken place over a large surface. Two entire islands have appeared where formerly the water was deep. Verlaten Island has been increased by two square miles, and extensive banks have been raised.

I should have been inclined to consider this as the sole cause of the great waves, more especially as it would entirely explain the somewhat remarkable fact that ships not far from the volcano at the time the wave was travelling from it, felt nothing of the stupendous undulation which rushed so far up the slopes of the hills.

We find, however, as will be seen when the eye observations at distant places are considered, that, besides the waves of long period, which after travelling thousands of miles were not of sufficient height to attract much notice, waves were observed by eye-witnesses following one another at rapid intervals of from five to fifteen minutes, and of heights of from two to three feet, though, from their short duration, they were not marked upon the gauges.

These seem to demand another cause, and it appears to me that they may be due to the large masses of the island blown away by the force of the explosions and falling into the sea, or, possibly, to the sudden displacement of the water over a submarine vent.

The missing mass of Krakatoa may be roughly estimated to be at least two hundred thousand million cubic feet (200,000,000,000). A fiftieth part of this mass dropping suddenly into the water would, by its displacement alone, furnish sufficient liquid to form a wave circle of 100 miles in circumference, 20 feet high, and 350 feet wide. The surrounding islands and shoals would, however, prevent a perfect circle being formed, and the wave might therefore be concentrated on certain parts of the arc, and be at some places higher than at others, varying according to the direction in which the masses fell. It has been remarked that this partiality of the waves was noticed.

I incline then to the opinion that the destructive waves in the Strait of Sunda were mainly due to these masses falling into the sea, or to sudden explosions under the sea after it flowed freely over portions of the former site of the island, possibly to both causes; but that the long wave which was recorded on so many tide gauges had its origin in upheaval of the bottom.

It does not appear unreasonable to assume that at the time of the great explosion of 10 o'clock, waves of both characters would be more or less synchronously formed.

I advance this hypothesis of the origin of the waves with some diffidence, but it appears to me not improbable from the known facts, and it would explain away some difficulties.

I cannot find any accurate observations bearing on the subject of the descriptions and heights of waves originating from a violent displacement of water on a large scale.

Two explosions have recently (October, 1886) taken place at Spithead. The first of 6,000 lbs. of gun-cotton in 10 fathoms water occurred on a very calm day. Unfortunately I knew nothing of it beforehand, and no one was on the look out for waves. Two officers, however, standing on the beach 4½ miles distant, noticed a wave approaching, and estimated its height at about two feet. It was followed by others at short intervals, but the number was not noted.

The tide gauge in Portsmouth Harbour, a very delicate instrument by Sir William Thomson, showed on its diagram no disturbance. The distance is 4 miles, but shoals and a narrow channel intervene, which possibly killed the wave, otherwise this failure to mark the wave might be taken as evidence that these short waves did not affect the gauge.

The second explosion of six mines of 500 lbs. of gun-cotton each, 45 feet below the surface in 60 feet of water, took place on 5th November, 1886. The mines were laid in a line about 100 feet apart. The day was stormy, and the surface of the sea much troubled.

The explosion threw up a wall of water extending along the line of mines, and estimated to be 150 feet high.

Only one observer on shore recorded any waves. He had provided himself with a small tube, in which a float carrying a light rod worked. The float worked incessantly from the action of the short wind waves, but he noticed that the whole body of the surface was raised at regular intervals. As his float hung at a certain point when falling, he was not able to register the depressions by it, but the observations for the crests were as follows :—

				Intervals.	
	h.	m.	s.	m.	s.
Explosion at	1	15	35	—	
Crest at	1	20	20	4	45
,,	1	22	30	2	10
,,	1	25	00	2	30
,,	1	27	45	2	45
,,	1	29	45	2	00
,,	1	31	30	1	45
,,	1	34	00	2	30

The height from crest to trough he estimates at one foot.

The first wave arrived at 4 mins. 45 secs. after the explosion, the site of which was $1\frac{4}{10}$ miles distant. The intervening mean depth is 6 fathoms. Theory gives a time of 4 mins. 12 secs. to traverse this distance.

It is to be remarked that the observer had no pre-conceived ideas as to the time the wave should arrive. His observations are therefore quite independent. He reports that the first phenomenon was a fall in the surface immediately followed by the first crest.

General Account of Data available, and the Mode of their Discussion.

To follow the movements of the wave which spread to distant shores, we have the indications of self-registering tide gauges and eye observations. The former only can be considered as accurate, but in some cases the latter give fair results. The tidal diagrams available are as follows :—

To the west of Krakatoa—

Andaman Islands	Port Blair.
East coast of Hindostan ..	Negapatam. Madras. Vizagapatam. False Point. Dublat.
In River Hoogly	Diamond Harbour. Kidderpore
West coast of Hindostan ..	Beypore. Bombay. Karachi.
South coast of Arabia	Aden.
South coast of Africa	Port Alfred. Port Elizabeth, Table Bay.
South Georgia Island	Moltke Harbour.
Tierra del Fuego	Orange Bay.
East coast Central America ..	Colon.
West coast of France	Socoa. Rochefort.
North coast of France	Cherbourg. Havre.
South coast of England.. ..	Devonport. Portland. Portsmouth. Dover.

To the east of Krakatoa—

North and East coasts of Java	Batavia (Tandjong Priok). Ujong Pangka. Sourabaya. Karang Kleta.
South coast of Australia	Port Adelaide. Williamstown.
New Zealand	Port Lyttelton. Dunedin.
East coast of Australia	Sydney.
Sandwich Islands	Honolulu.
Alaska	St. Paul's, Kodiak.
West coast of North America	Saucelito, San Francisco.

Of eye observations, we have reports to the west of Krakatoa from—

West coast of Sumatra	Padang.
South-west coast of Ceylon	Galle. Colombo.
East coast of Ceylon	Arugam. Batticaloa. Trincomalee. Mullaittivu. Point Pedro.
Seychelles Islands	Mahé.
Cargados Garajos	Avocaire Island.
Rodriguez Island	Mathurin Bay.
Mauritius	Port Louis.

To the east of Krakatoa, from—

West coast of Australia	Cossack. Geraldton.
New Zealand	Various places.

Throughout this paper the following is the sense of different terms:—

The height of the wave is the height of the crest above the normal level of the water at the time.

The range of the wave is the vertical distance from crest to trough.

The length or amplitude of the wave is the distance in geographical miles from crest to crest.

The original diagrams from the automatic gauges are on every conceivable scale, for both height and time. Some are kept in civil, some in astronomical, time ; some record the height in mètres, some in feet; some work from left to right, others in the opposite direction.

The copies accompanying this paper are reduced to one uniform scale, convenient for publication, of $\frac{1}{3}$ of an inch to a foot, and $\frac{1}{6}$ of an inch to the hour, except the curves for Socoa, Rochefort, Cherbourg, and Havre, which are on a larger scale, so that the minute fluctuations may remain visible. These show the heights in feet, at local civil time, counting from midnight to 24 hours. (*See* Plates XVII. to XXXV., p. 150.)

In calculating the time of translation in the tables I have reduced all the times to Greenwich civil time; but in speaking of the waves, I mention the local time.

The indications of the arrival of the wave on these diagrams are by no means always precise; and the variety in the appearance of the diagrams is very marked. In all cases they show long continued disturbance; but the complication of the waves in some is as remarkable as the regularity of the series is in others. In all cases the more prominent waves are, unlike those registered at Batavia, preceded by minor oscillations, which in some instances merge so insensibly into the higher waves that it is difficult to identify any one wave as the first of what may be called by comparison the greater disturbance.

Seeing that several large waves reached the shores of Sunda Strait before the great one of 10 o'clock, it would not be surprising to find that these earlier waves occur on the diagrams, were it not for the very slight indications of them marked on the Batavia gauge. The path, however, to the westward is so much more open that these possibly shorter waves found their way across the Indian Ocean, while they were killed by the sudden expansion into the Java Sea.

On the east coast of India the arrival of the greater disturbance is unmistakable; which is probably due to the shorter distance and the unimpeded course of the waves in deep water. Here also there appears to be but one series of the larger waves for at least some hours; but at places further removed, several series of long waves can be made out, which much interfere with the regularity of the diagrams.

The position of some of the gauges, inside bars, up rivers, and in similar places not open to free access from the sea, may have had some effect on the appearance of the diagrams.

Another cause of variety is the difference in the construction of the gauges. When the orifices in the tube which admit the water are too large, local waves appear to affect the record.

Assuming from the well-marked character of the waves shown on the Batavia diagram that the period of the waves that left Krakatoa was about 2 hours, I have, in my investigation of the diagrams, first examined them to see whether the same period can be identified. In this I have met with imperfect success. Though in many cases such a period can be found, it is frequently only to be arrived at by taking every alternate wave, the intermediate ones being nearly half-way between those selected. It thus appears either as if the original waves had in their long course divided and doubled themselves, or as if the great wave reflected from the eastern shores of the land bounding the Strait of Sunda was the cause of the intermediate waves, the distance of these shores being such as would cause the time elapsing between the primary and reflected waves to be roughly a moiety of the long period of 122 minutes recorded at Batavia.

At the very distant stations, as Orange Bay, and the ports of the English Channel, the wave period is, in some instances, roughly one-fourth of the original period of Batavia ; which looks like a still further sub-division of the waves ; but there are exceptions.

In all cases I have taken the first of a recognisable series of higher waves as being identical with the great 10 o'clock wave from Krakatoa, though generally the maximum wave follows at a longer or a shorter interval.

The speeds that are thus deduced should be, therefore, those of the great wave ; the previous undulations, though sometimes—as far as height is concerned—merging somewhat insensibly into the accepted waves, not agreeing with them in period. The speed, moreover, that would correspond with these earlier waves in most of the diagrams would be so high as to place them beyond the bounds of probability.

I have given the speed calculated from the formula $V = \sqrt{gh}$, and the corresponding depth in fathoms of the water over which the wave has travelled, as well as the probable mean depth from the known soundings on the line.

A direct comparison can thus be made between the theory and the known facts ; and although the soundings obtained are in some cases scanty, and in others altogether wanting, it will be seen that in such instances where material exists, the comparison is always to show that the wave has travelled at a slower velocity than theory demands. Against this conclusion must be stated the consideration that any unknown ridges would diminish the speed ; but these must be large, or the portion of the wave overlapping them would still travel at the speed due to deeper water, and over a very slightly longer course.

It will be seen that the first great wave is sometimes preceded by a considerable fall, or negative wave. From the fact of the Batavia gauge showing as the first indication an unmistakable sharp rise, I conclude that the original disturbance propagated from Krakatoa was a positive wave, and that this depression is merely due to the fact of smaller waves preceding the greater disturbance, whatever may have been the reason of their existence.

In the discussion of each diagram, I have given the period of the series of waves, both of those which seem to correspond with the two-hour period, and of the shorter series of which these are made up.

I have presented in a tabular form the main results of the investigation into the time of translation of the disturbance.

To arrive at the most probably accurate estimate of the velocity of the wave between Krakatoa and the different places, I have taken from the large scale charts of each harbour and coast, when sufficient data are forthcoming, the distances over which, in approaching the tide gauge, the wave would have to travel in shallow water, that is, water under 1,000 fathoms.

For these distances I have calculated the time which the wave would occupy in traversing them, according to the depths, by the formula $V = \sqrt{gh}$, and subtracting this time and distance from the total, the remainder will give the time taken by the wave in crossing the deeper intervening space. This gives a better means of judging whether the disturbance can be considered truly to have emanated from the volcano, as the smaller depths, in which the change of velocity is most rapid, are thereby eliminated.

Unfortunately, in many instances the soundings are not carried far enough from the shore to show where the 1,000 fathom line is.

In one of the columns in the table I give the outermost soundings available.

It is to be regretted that at the outset, from Krakatoa itself, the soundings are so sparse that it cannot be determined with any exactitude where the 1,000 fathom depths begin, but I have taken it as 50 miles from the island, and have, from the few depths given, calculated 16 minutes as the probable time when the wave would reach this depth, and henceforth travel in deeper water over the Indian Ocean. I have therefore subtracted this 50 miles and these 16 minutes from the distances and times of every wave leaving Krakatoa by the west.

The distances have been in all cases taken as the shortest, *i.e.*, have been measured on a great circle, or on several arcs of great circles, when land, islands, or banks intervene.

Though Sir G. AIRY, in his article in the 'Encyclopædia Metropolitana,' states that it is only when the amplitude of the wave is one thousand times the depth of the water that the simplified form $V = \sqrt{gh}$ of his general equation can be taken as accurate; the difference between the depths thus calculated and those by the more nearly exact equation, is so small, when dealing with these waves which appear to have an amplitude of over one hundred times the depth, that, considering the inexactness of the times and the doubt as to the identification of the right wave, I have used the simpler form.

To the eastward of Krakatoa, or into the Java Sea, the wave does not appear to have been noticed at any great distance. Thanks to the tide gauges, three in number —erected in the Strait of Sourabaya—indications of its presence there exist; but its maximum height is only 10 inches, too insignificant a disturbance to be otherwise noticed.

We do not find that it was observed beyond Sourabaya, which is 440 miles from Krakatoa.

To the great and sudden expansion of the area in which the wave would find itself on emerging from the narrow portion of the Strait of Sunda, north of Merak; to the general shallowness of the Java Sea ; and to the interposition of banks and islands, is doubtless due this small extension of the disturbance to the east and north.

The automatic tide gauge at Singapore showed no disturbance, nor was anything remarked at Hong Kong.

The wave at Merak was, say, actually 50 feet high, having travelled over an average depth of 29 fathoms for 34 miles.

Up to this point, however, the sea is open, and no interference by reflection or otherwise would take place ; but a gradual closing of the passage towards the end would probably tend to raise its height.

Immediately, however, after passing the strait, 10 miles wide, on one side of which Merak is situated, the height of the wave must have rapidly diminished on its expansion in the Java Sea. Thus we find at the North Watcher, a small island in the open sea, 53 miles beyond Merak, and 82 miles from Krakatoa, that its height was reduced to 8 feet, as reported by the lighthouse keepers in the island. The average depth over which the wave would travel from Krakatoa to the North Watcher is 22 fathoms, the course being nearly in a straight line. At Dindang, 240 miles from Krakatoa, the wave was 4½ feet high, having travelled in a straight line over an average depth of 16 fathoms. The same is found in the other direction from Krakatoa. At Vlakke Hoek Lighthouse, 54 miles in a straight line from Krakatoa, the water rose 50 feet ; but at Benkunat, 36 miles further—but round the corner—it was barely noticed.

Table I. gives the statistics for the places near Krakatoa, and Plate XXXIV. will show their positions better than any description. The height of waves must, however, be regarded as only approximate, as they are all from eye observations and reports only.

TABLE I.

Showing height of wave in the immediate vicinity of Sunda Strait.

		Time from Krakatoa.		Distance in sea or geographical miles.*	Average depth in fathoms.	Height of wave in feet.	Situation as regards free access for wave.
		Hours.	Mins.				
Strait of Sunda.	Tyringin	..	..	24	29	50 ?	
	Anjer	..	..	26	31	50 ?	
	Merak	..	..	33	29	50 ?	
	Kalianda	..	..	27	21	50 ?	
	Telok Betong	..	..	38	17	50 ?	
	Vlakke Hoek	..	..	54	100	50 ?	
	North Watcher Id.	1	30	82	22	8	In open sea in straight line from Krakatoa.
	Tjabang	..	..	95	17	4	Open, but reefs.
	Dindang	7	30	240	16	4½	Open, but reefs, in stright line from Krakatoa.
North Coast of Java.	Bantam	..	..	50	26	6	Only 15 miles round the peninsula of Merak, where the wave was 50 feet.
	Lontar	..	..	55	24	7½	Open.
	Kramat	..	..	77	27	11	Open.
	Batavia (T. Prick)	2	30	100	28	6	Open, but many reefs.
	Tjilinting	2	30	102	28	2	Close to east of Batavia, but protected.
	Tji Lamaya	4	30	145	25	2	Open bay, but screened to west.
	Rambatan	6	00	184	22	2	Open.
	Japara	8	00	310	17	1½	Open.
	Ujong Pangka	10	32	440	26	⅔	Open.
South Coast of Sumatra.	Winkoops Bay	..	..	147	200	5	Open.
	Tyliatiap	7	00	330	200 ?	6	Fairly open.
	Benkunat	..	..	90	300 ?	very slight.	30 miles round corner of Vlakke Hoek.
	Kroë		..	130	300 ?	none.	60 miles round corner of Vlakke Hoek.
	Sambat	..	..	160	350 ?	6	Open to wave.
	Manna	..	.	210	350 ?	3	Bay protected from direction of wave.
	Pino	.	..	215	350 ?	7	5 miles from Mannâ, but exposed.
	Bencoolen	..	..	265	300 ?	3	Protected by reefs.
	Moeko-Moeko	..	..	370	300 ?	4	Open to wave.
	Painan	..	..	455	?	9	Bottom of bay open to wave.
	Padang	3	46	490	?	..	Open to wave, but many reefs.

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* An average geographical or sea mile is 2,025 yards, or about 1·15 English mile.

TIDAL DIAGRAMS.

JAVA.

There are three automatic tide gauges east of Batavia, all in the island of Java.

Ujong Pangka.

This is on the north coast of Java, 340 miles east of Batavia. The tide gauge shows disturbance of an irregular character, in which no period can be recognised. A small wave occurs at 17 hrs. 45 mins., but a decided rise is shown at 21 hours, which I take to be the great wave. Its height is about 9 inches. This time will give a velocity of 42 miles an hour, which agrees almost exactly with that deduced from the formula $V = \sqrt{gh}$. The depths from off Batavia, up to which spot the track of the waves to the two places is identical, average about 25 fathoms, but vary considerably. The disturbance lasts 19 hours.

It is rather astonishing that the regular waves which are registered at Batavia should have entirely disappeared by the time the disturbance reached this gauge. The long extent of shallow water and the strong currents which frequently prevail off this coast may account for the breaking up of the regularity.

Ujong Sourabaya.

This gauge is placed on a point half-way through the narrow and shallow strait of Sourabaya. The disturbance is as slight and irregular as at Ujong Pangka, and I take the first distinct wave crest at 22 hrs. 25 mins. for comparison.

The distance from Ujong Pangka, which stands at the entrance of the strait, is 25 miles, with an average depth of 4½ fathoms.

This should require 1 hr. 36 mins. to traverse, whereas the time registered is 1 hr. 24 mins.—a very close agreement when the circumstances of the channel are considered.

Karang Kleta.

This gauge is on a small rock at the southern end of Sourabaya Strait. The disturbance is again irregular, but bears a marked resemblance to Sourabaya, from which it is distant 14 miles, with an average depth of 4 fathoms. The wave which corresponds to that at Sourabaya is, however, registered 25 minutes earlier than at that place, which makes it to have travelled over the strait from Ujong Pangka in an hour, instead of 2 hrs. 27 mins., which is given by theory. This discrepancy is not easy to explain.

INDIA.

The report furnished in December, 1883, by Major Baird, R.E., in charge of the tidal survey of India, has been already communicated to the Royal Society.*

The account of the disturbance at each tidal station in India, as taken from the original diagrams, is given in great detail, and all the interesting points are discussed by Major Baird. His report also contains statements of the phenomena noticed at other places where no gauge was at work.

We now possess much fuller information on many of the occurrences external to India than was available when Major Baird wrote his paper; and, with the consent of the Committee, I do not purpose to reproduce the paper, as it would be difficult, without destroying its connected character, to remove those portions which are founded on insufficient data.

I have re-discussed the data furnished by the Indian gauges from a somewhat different point of view from that adopted by Major Baird, founding my selection of waves on the small-scale diagrams furnished by him, and checking the times of arrival of the waves by his detailed account, taken from the originals as given in his paper.

Port Blair.

This bay in the Andaman Islands, 1,480 miles from Krakatoa, is the nearest place furnished with a gauge to the west of the Strait.

From 3 hours of the 27th a very small oscillation is shown, which increases at noon; and at 13 hrs. 55 mins. a very distinct wave, with a height of 7 inches, appears. This is the first of a long series given below—

	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.
Times ..	13 55	14 53	16 03	17 09	18 05	19 14
	m.	m.	m.	m.	m.	m.
Intervals ..	58	70	66	56	69	48
Times ..	20 02	21 12	22 35	23 15	0 12	1 20
Intervals ..	70	83	40	57	68	55
Times ..	2 15	3 15	4 30	5 30	6 40	7 35
Intervals ..	60	75	60	70	55	

The double intervals are—

128 122 117 153 97 123 135 130 minutes.

This gives a mean interval of 62 minutes, or, for every other wave, of 2 hrs. 06 mins.—nearly the Batavia interval.

Taking the 13 hrs. 55 mins. wave for comparison, the velocity for the distance of 1,480 miles is 308 miles an hour from shore to shore. Unfortunately, in this case,

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* 'Proc. Roy. Soc.,' vol. xxxvi., pp. 248–253.

no data exist for eliminating the wave near the Andaman shore, but the wave has probably travelled at about 320 miles an hour, which would give a mean depth of over 1,500 fathoms.

Negapatam.

The position of this gauge is just inside the bar of the river, but the coast is straight and open. The diagram shows, as at Port Blair, a small oscillation from midnight to 13 hours of the 27th, when a distinct wave of 9 inches in height is registered as the first of a series of eleven waves, of a mean period of 68 minutes, or, taking every alternate wave, 2 hrs. 10 mins., which again is not very different from Batavia.

	h. m.		h. m.		h. m.		h. m.		h. m.		h. m.	
Times ..	14 40		16 05		16 48		17 50		18 52		19 43	
		m.		m.		m.		m.		m.		m.
Intervals ..		85		43		62		62		51		67
Times ..	20 50		21 50		23 09		24 00		1 32		3 10	
Intervals ..		60		79		51		92		98		

The double intervals are—

128 124 118 139 143 minutes.

The distance is 1,805 miles between the 1,000 fathom depth off the Sunda Strait and 150 fathoms off Negapatam, the known soundings not extending to deeper water. This, taking the 14 hrs. 40 mins. wave, gives a velocity of 357 miles an hour, which corresponds to a mean depth of 1,880 fathoms.

Arselar River, Karikal.

At this port, 10 miles north of Negapatam, there is no self-registering tide gauge, but the attention of the Port Officer was called to the movement of the water.

He reports that at 2 o'clock in the morning of the 27th, a small disturbance was visible in the river, which continued all the morning. After 11 o'clock the waves succeeded one another with greater rapidity, and with gradually increasing height. Between 13 hours and 15 hours they were of about 22 inches range, with a mean interval of about 45 minutes. From 4 o'clock they began to diminish, disappearing entirely by 11 hours of the 28th.

The maximum height here corresponds with the record of the diagram at Negapatam, though the mean interval mentioned is less, 45 minutes instead of 68. This is the only case on the coast of India, in which eye observations can be compared with a diagram at no great distance. As far as height goes they agree, nor does the interval differ so much as do those of the waves observed in Ceylon.

The only waves, therefore, noted here appear to be of a similar character to those recorded on the gauges.

Madras.

This gauge is situated inside the artificial port, and is fitted with very small inlet holes at the bottom of the tube, the local swell being ordinarily great. The diagram is in consequence very smooth, and exhibits quite a different appearance from the majority of the others. The disturbance begins abruptly at 14 hrs. 33 mins. on the 27th, the first of a series of ten waves with very irregular periods, the mean of which is 87 minutes. This is quite different from the period of the other gauges, and is rather incomprehensible.

	h. m.	m.	h. m.	m.	h. m.	m.	h. m.	m.	h. m.	m.	h. m.	m.
Times ..	14 33		16 27		17 48		19 33		21 00		22 20	
Intervals ..		114		81		105		87		80		67

Times ..	23 27		0 40		2 30		3 54		5 07
Intervals ..		73		110		84		73	

The distance is 1,863 miles from the 1,000 fathom line off Sunda Strait to the 100 fathom line off Madras; and taking the 14 hrs. 33 mins. wave, the velocity comes out 338 miles an hour, which gives a mean depth of 1,700 fathoms.

Vizagapatam.

This diagram is remarkable for the large number of small oscillations shown throughout. These are in all probability due to the construction of the orifices admitting the water to the tube, which permits waves of short period, whether local or subsidiary to the seismic disturbance, to be registered. The result is to much confuse the record. The first appearance of the larger waves on the diagram bears a strong resemblance to those at Port Blair, but afterwards they lose their individuality and it is difficult to recognise them. The first large wave of 6 inches in height is at 15 hrs. 14 min., and eight other waves may be selected with a mean period of 77 minutes, or a period for the double waves of 2 hrs. 34 mins.

	h. m.	m.	h. m.	m.	h. m.	m.	h. m.	m.	h. m.	m.	h. m.	m.	h. m.	m.	h. m.	m.	h. m.
Times ..	15 14		16 33		17 33		19 03		20 28		21 45		22 55		0 10		1 30
Intervals		79		60		90		85		77		70		75		80	

The double intervals are—

h. m.	h. m.	h. m.	h. m.
2 19	2 55	2 27	2 35

It is useless to try to follow the waves further, though the disturbance lasts to 21 hours on the 28th, or for 30 hours. The 15 hrs. 14 mins. wave gives a velocity of 338 miles an hour for the distance of 1,909 miles, measured from the 1,000 fathom line off Sunda Strait to the 100 fathom line off Vizagapatam.

False Point.

This gauge is situated in shallow water on the inshore side of a long sandy spit, which projects parallel to the main line of coast, and the wave has to travel over a long distance in shallow water before it reaches the gauge. The outermost sounding is 23 fathoms, and the bank probably extends much further to seaward.

The diagram is remarkably free from short waves of all kinds, and the only ones registered are those of a mean period of 2 hrs. 42 mins., of which six can be traced.

	h. m.		h. m.		h. m.		h. m.		h. m.		h. m.
Times ..	16 36		19 30		22 15		1 05		3 20		6 05
		h. m.		h. m.		h. m.		h. m.		h. m.	
Intervals ..		2 54		2 45		2 50		2 15		2 45	

The height of the largest wave, the second, is 14 inches, which much exceeds that at any of the other Indian stations. This is probably due to the long extent of very shallow water.

The 16 hrs. 36 mins. wave gives a velocity of 308 miles an hour for the distance of 2,003 miles, measured from the 1,000 fathom line off Sunda Strait to the 23 fathoms off False Point. This corresponds to a mean depth of 1,400 fathoms; but if the extent of the bank off False Point were known, this mean depth for the ocean course would probably be indicated as considerably greater.

Dublat.

This gauge, at the entrance to the River Hoogly, is situated in a position fairly open to the sea, but the coast is faced with wide banks over which the waves must pass.

The diagram is free from short undulations, which much facilitates the recognition of individual large waves.

Twelve waves of a mean period of 65 minutes, commencing with a well marked one of 8 inches at 17 hrs. 56 mins., can be followed. The period of the double waves is 2 hrs. 7 mins., which brings us back to the Batavia period again.

	h. m.		h. m.		h. m.		h. m.		h. m.		h. m.	
Times ..	17 56		18 50		19 52		21 00		21 55		22 57	
		m.		m.		m.		m.		m.		m.
Intervals ..		54		62		68		55		62		66
Times ..	0 03		1 10		2 15		3 25		4 30		5 05	
Intervals ..		67		65		70		65		80		

The double intervals are—

h. m.	h. m.	h. m.	h. m.	h. m.
1 56	2 03	2 08	2 12	2 15

The distance, measured from the 1,000 fathom line off Sunda Strait to the 150 fathom depth off Dublat, gives a velocity of 351 miles an hour, which corresponds to a mean depth of 1,820 fathoms.

Diamond Harbour.

This gauge is situated in the River Hoogly, 40 miles from Dublat.

Only one wave is marked on the diagram, which arrived at 20 hrs. 6 mins.

It took, therefore, 2 hrs. 10 mins. to travel this distance, which agrees exactly with the time taken by the tide wave, the disturbance in each case occurring at the local high water. The time required by theory to travel this distance over the shallow water of the river, which averages 6 fathoms, at this time of tide, is 2 hrs. 0 min.

Kidderpore.

This place is close to Calcutta, on the Hoogly, and is 40 miles above Diamond Harbour.

Here also only one wave is recorded, which, like that at Diamond Harbour, has travelled at the same pace as the tide wave, and arrives at high water, or 2 hrs. 05 mins. after the wave at Diamond Harbour. The time required by theory is 1 hr. 45 mins. for the average depth of 8 fathoms, but the channel is narrow and tortuous, and the depths vary from 11 fathoms to 3 fathoms, a change which would doubtless tend to impede the wave. The wave was 3 inches high.

Beypore.

This gauge is situated on the west coast of Hindustan. The diagram is very free from waves of short period.

An irregular small oscillation, but of longer periods than at Negapatam, to which this diagram bears a resemblance, is shown from the beginning of the diagram at 0 hour of the 27th to 15 hrs. 57 mins., when a large wave of 8 inches suddenly makes its appearance. This is the first of a long series that can be followed for nineteen waves. These have a mean period of 58 minutes, or, for the double waves, 1 hr. 56 mins.

	h. m.	m.	h. m.	m.	h. m.	m.	h. m.	m.	h. m.	m.	h. m.	m.	h. m.	m.
Times ..	15 57		17 00		17 40		18 40		19 48		20 35		21 35	
Intervals ..		63		40		60		68		47		60		57
Times ..	22 32		23 25		0 25		1 30		2 20		3 05		4 20	
Intervals ..		53		60		65		50		45		75		75

	h. m.		h. m		h. m.		h. m.		h. m.
Times ..	5 35		6 35		7 30		8 25		9 20
		m.		m.		m.		m.	
Intervals ..		60		55		55		55	

The double intervals are—

103 128 107 110 125 95 150 115 110 mins.

The distance, measured from the 1,000 fathom line off the Strait of Sunda, to the 1,000 fathom line off Beypore, is 2,090 miles; and the 15 hrs. 57 mins. wave gives a velocity of 326 miles an hour, corresponding to a depth of 1,600 fathoms. The largest wave is at 5 hrs. 35 mins., or 13½ hours after the first one, and is 16 inches high. The track of the wave is unfettered, but it has to turn Cape Comorin.

Bombay.

This gauge is situated on the inner side of the peninsula forming the harbour, which is, however, open to the south, whence the wave would come.

The wave, after passing Beypore, would travel inside the Laccadive Group, where the depths are—as far as they are known—sufficient to permit it by this route to outstrip the undulation which would pass through the Nine Degree Channel and then turn to the north; a longer course, but in deeper water.

On approaching Bombay the wave must pass over a good deal of shallow water. The diagram shows one crest only of any magnitude, at 18 hrs. 50 mins. This is at high water, and a very small disturbance is recorded at the succeeding low and high water. The distance from the 1,000 fathom line off Sunda Strait to the probable position of the 1,000 fathom line off Bombay is 2,483 miles; and the velocity is 336 miles an hour, corresponding to a depth of about 1,700 fathoms. The height of the wave may be taken as 6 inches.

It is very remarkable that the disturbance should be confined to this single wave, but the run of the tidal streams is very strong in Bombay Harbour.

Karachi.

Here the tide gauge is in the narrow estuary forming the harbour. A very small oscillation appears at 5 hrs. 30 mins. on the 27th, which is continuous until the first great wave at 18 hrs. 40 mins. This wave is preceded by a well marked negative wave, but the crest preceding is not in accordance with the subsequent period, and is too small to be taken as the wave corresponding to those selected in the other Indian Diagrams. The 18 hrs. 40 mins. is the first of a series of sixteen waves, and is 12 inches high. The mean period, omitting the last wave, is 69 mins., and for the double waves 2 hrs. 18 mins.

	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.
Times ..	18 40	19 56	20 50	21 55	23 10	0 35	1 50
	m.	m.	m.	m.	m.	m.	m.
Intervals ..	76	54	65	75	85	75	70
Times ..	3 00	4 15	5 15	6 30	7 30	8 30	9 40
Intervals ..	75	60	75	60	60	70	70
Times ..	10 50	12 30					
Intervals ..	100						

The double intervals are—

h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.
2 10	2 20	2 40	2 25	2 15	2 00	2 20

The distance, measured from the 1,000 fathom line off Sunda Strait to the probable position of the 1,000 fathom line off Karachi, passing through the Nine Degree Channel, and to the northward outside the Laccadive Islands, is 3,032 miles, for which the 18 hrs. 40 mins. wave gives a velocity of 340 miles an hour. This corresponds to a mean depth of 1,710 fathoms; whereas the probable depth from existing soundings is 2,150 fathoms. In several parts of the route, however, the chart is a blank, and notably in the Nine Degree Channel.

The disturbance lasts until the end of the diagram, or till 22 hours of the 28th.

Aden.

The tide gauge is at Steamer Point, that is, in the bay behind the peninsula of Aden, protected from the advancing wave, which would have to change its course 180° to reach the gauge.

The wave would travel over 9 miles of shallow water in so doing. The diagram is free from waves of short period.

The disturbance is inappreciable until 13 hours on the 27th, when a small wave of 2 inches appears. After two others, a decided wave of 5 inches is recorded at 17 hrs. 50 mins.

This is the first of seventeen waves at fairly equal intervals, which can be followed with a mean period of 67 minutes; or for the double waves 2 hrs. 14 mins.

	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	
Times ..	17 50	18 50	19 50	20 50	22 10	23 10	23 55	1 05	
	m.	m.	m.	m.	m.	m.	m.	m.	
Intervals..	60	60	60	80	60	45	70	70	
Times ..	2 15	3 25	5 00	6 00	7 18	8 10	9 00	10 15	11 45
Intervals..	70	95	60	78	52	50	75	90	

The double intervals are—

h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.
2 00	2 0	1 45	2 20	2 45	2 18	1 42	2 45

The distance, measured from the 1,000 fathom line off Sunda Strait, through the Nine Degree Channel and north of Sokotra, to the 1,000 fathom line off Aden, is 3,642 miles.

The 17 hrs. 50 mins. wave gives a velocity of 347 miles an hour, corresponding to a mean depth of 1,770 fathoms. The probable mean depth from known soundings is 2,100 fathoms.

CEYLON.

EYE OBSERVATIONS.

The report of the Surveyor-General of Ceylon, reproduced on pp. 116 to 124, is interesting in many details. Unfortunately it does not furnish any precise data on the points of time and height of the wave. In one respect, however, it is very worthy of consideration.

At all the places where the disturbance was remarked, the observers agree that the period of the wave was comparatively short. From 5 to 20 minutes are named as elapsing between successive crests. Now this is quite different from all the diagrams from gauges—which show only long waves; and it is much to be regretted that no gauge by which comparison might have been made between eye observation and mechanical record was at work at any of these places.

At no Indian tidal station are any short waves shown, of any height greater than 3 or 4 inches; and at Negapatam, which is only 100 miles further off, and which, except for being inside a bar, is equally favourably situated for receiving the waves—only one period of under an hour, viz., 43 minutes, is recorded.

Eye observations of this description are very liable to error, especially in point of height; but when many independant observers at different places agree fairly, the evidence is much strengthened.

The range at Galle is estimated at 8 feet, at Colombo 7½ feet, at Valluwedditherai 4 feet, at Trincomalee 8 feet, Batticaloa 8 feet, Arugam 4 feet, Hambantota 12 feet.

These short waves must probably be regarded as super-seismic waves; that is, waves of short period, but of greater height, imposed on the longer wave that alone affected the gauges. Their duration was brief compared with that of the long waves recorded on the diagrams.

There does not seem to be any difficulty in assuming that these waves were in their origin synchronous with the longer undulations, and their speed of translation would be about the same. It is, therefore, not surprising to find the time of their arrival agreeing very well with that of the longer waves, as far as the incomplete information admits of comparison.

At Batticaloa, however, the first wave of 24 inches was noted at 7 hours on the 27th. This is 1 hr. 28 mins. Greenwich time, or one hour and a half before the great wave left Krakatoa. It must, therefore, have been due to one of the earlier waves.

Assuming that it travelled at a speed of about 350 miles an hour, this wave must have left the Strait of Sunda at about 3.40 a.m. There is, however, no large wave recorded in the Strait at or about this time, none being noted as reaching the shores between 1.30 and 6.

To what this early disturbance at Batticaloa was due is therefore a mystery. The largest wave is, however, stated to have occurred at about noon, which agrees with the Galle observations.

The Surveyor-General's Report on Tidal Waves on the Coast of Ceylon, resulting from the Eruptions in the Strait of Sunda on the 26th and 27th August, 1883.

Surveyor-General's Office, Colombo,
10th April, 1884.

Sir,

With reference to your notice of February 12th in 'Nature' of February 14th, page 355, I have the honour to report to you the result of my inquiries regarding the effects, as observed in Ceylon, of the eruptions at Krakatoa, in the Strait of Sunda, on the 26th and 27th of August last. The various stations from which I have received reports are marked on the accompanying map.

The questions asked were :—

(*a.*) The extreme rise and fall of tide, and the number of times the wave appeared to come and go?
(*b.*) Whether noises were heard or any motion of the earth felt?
(*c.*) The exact time as near as obtainable?
(*d.*) Whether any crack or fissure had been observed inland or along the coast?

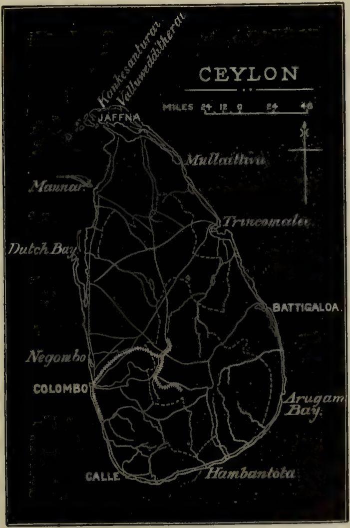
Galle.—The Master Attendant reports that four unusual waves were noticed in the port at the hours of one, two, three, and half-past four on the afternoon of August the 27th, the last of which he witnessed himself, and recorded as follows :—" A very unusual receding of the sea, the small boats at their usual anchorage being left by it—a thing I had never seen before during my tenure of office, since 1860.

" It was about 1½ minutes in recession, and then about the same time in a sort of suspensory standstill, when it commenced quietly to rise again, taking about the same 1½ minutes to reach the level of our highest high water-marks, thus making, from the lowest mark of recession to it, a difference of 8 feet 10 inches.

"The usual tide rise and fall here is about 2 feet, and so the great difference caused by this disturbance was palpably from unusual recession."

Colombo.—The Master Attendant reports :—"I find it difficult to get at the exact hour of the commencement of the tidal disturbance in this harbour, but I am informed by the man in charge of the landing jetty that about 2.30 p.m. on the 27th of August there was a sudden rise of the sea to about 15 inches above the highest spring tide, and that shortly afterwards, within 15 minutes, the sea fell to about 3 feet below the lowest spring tide. I witnessed between 3.30 and 4.30 p.m. four rises and falls of the sea, and, as near as I can judge, there were 7 feet 6 inches between the highest point to which the sea rose and the lowest point to which it fell.

Fig. 12.



During this time there was a strong current in the harbour, which carried away the stern moorings of some of the steamers in port, and swung them round against the wind. The tidal disturbance went on more or less till 8 p.m. of the 27th, and I observed it again the next day about midday, but the rise and fall of the tide then did not exceed 1 foot."

Negombo.—The information from this station is very meagre. The Mudaliyar of Alutkuru Korale North reported to the Assistant Government Agent :—"No changes in the sea or land occurred on the day in question.

"I am informed that there had been an unusual ebb tide and flood tide twice within half-an-hour in the mouth of the lake."

I have had no reports from Chilaw or Puttalam, but Mr. VIGORS, the Police Magistrate of Kalpitiya (Calpentyn), sent me an interesting and quaint report from Mr. VANSANDEN, the Preventive Officer at Dutch Bay, which I give verbatim, as in one paragraph, where he describes the wash-away of a belt of land about 2 or 3 chains in extent, including the burial ground, it appears as if the dead had sought shelter with the living in a neighbouring cocoa-nut garden!

"The so-called tidal wave had been felt here, too, on the 27th ultimo, about 3 o'clock p.m. The tide is said to have been observed coming in and going out three or four times in the space of one hour; this had been witnessed by the fishers who had been out at sea. The rise of the tide was so much above the usual water-mark that many of the low morasses lying in close proximity to the seaside were replete with water that flowed into them. However, the water thus accumulated did not remain long, but, forming into a stream, wended its course in a southerly direction, through low lands, to a distance of nearly a quarter of a mile, and found a passage back to the sea; thus the water that had so abruptly covered up such an extent of land did not take many days in draining off.

"Eke, I must say that the receding waters were not slow behind in their action, for they washed away a belt of land about 2 or 3 chains in extent, including the burial ground situated on the coast to the south-west of the bay, designated as the Parava's or Fisher's Quarters, compelling the inhabitants to seek shelter in a neighbouring cocoa-nut garden.

"On the above date noises were heard by several persons, resembling the rumbling of distant thunder, or rather that of the booming of cannon, which lasted from 7 to 10 a.m.

"No motion of the earth was felt, nor have I heard of any crack or fissure having occurred either inland or along the coast in the vicinity."

Mannâr.—The reports from this station are conflicting, and it is very doubtful whether any sudden rise or fall of the sea was actually witnessed there by anyone. Mr. FOWLER, the Assistant Government Agent, reported:—"I have caused careful inquiry to be made on the subject, but find that no rise or fall of the sea was noticed here on the 27th ultimo, although loud sounds, resembling the report of distant cannon, were heard to the eastward on that date.

"I may mention that there has been a curious change in the colour of the sun's disc noticed in the early morning and in the evening since the 9th instant [September, 1883]. It has appeared to be of a bluish-green colour."

In reporting on the state of the Searchers' House at the South Bar, the Sub-Collector of Mannâr wrote on September the 17th to the Collector of Customs at Jaffna as follows:—"I went to see the house on Saturday afternoon, and found it to be very much damaged, the sea having washed away a great part of the sand put for the floor of the building, although the building is at a distance of about 255 feet from the sea. The sea appears to have risen all of a sudden, during the latter part of last month."

In forwarding a copy of this report, Mr. TWYNAM, the Government Agent, says: —"It appears that there must have been something unusual in the tide off the southern coast of Mannâr in August;" but he adds:—"I was told by the gentlemen who came up in the '*Serendib*' with Mr. Justice CLARENCE that they were informed that nothing was observed at Paumben."

It may be inferred from this that the strength of the tidal wave had become very much modified or exhausted by the time it reached the Gulf of Mannâr; and from a further report of the Assistant Government Agent I am inclined to the belief that the damage done to the Searchers' House was not caused by the tidal wave. Mr. TWYNAM goes on to say:—"Nothing unusual was noticed in Jaffna or at Kaits in regard to the tide. No one seems to have heard any peculiar noises in Jaffna, or to have felt any motion of the earth.

"I have not yet received any information of any crack or fissures having been observed anywhere on the coast."

Mr. TWYNAM has furnished me with reports also from the Sub-Collectors of Kankesanturai, Valluwedditherai and Point Pedro, on the most northerly part of Ceylon on the Bay of Bengal exposed to the north-west roll or wave from the Strait of Sunda, from which I quote as follows:—

Kankesanturai.—"The extreme rise and fall of the tide, though not noted, was about 2 to 3 feet; and the number of times the tide appeared to come and go, though not counted over at the time, would be about 3 or 4 times. No noises were heard, nor was any motion of the earth felt on the occasion. Though the exact time cannot be stated, it was first noticed about midday, when a boat with import cargo at the wharf was said to have got aground all of a sudden."

Valluwedditherai.—"The usual rise and fall of the tide at this time of the year is from 2½ to 3 feet; on the 27th ultimo the rise was, at its maximum, 2 feet more than ordinary; the highest rise was at about 2.30 p.m The number of times the waves appeared to advance and recede was about 10 or 12.

"A man of this place informed me that he counted 16 times from 12 to 3 p.m., in which the wave appeared to come and go.

"No noises were heard, nor was any perceptible motion of the earth felt.

"The exact time was not noted, but it was about a quarter past 12 p.m. that the rise in the tide was observed.

"No cracks or fissures have been observed either inland or along the coast."

Point Pedro.—August the 29th, 1883.—"A strange phenomenon, such as had never been witnessed before by the oldest masters of vessels and others belonging to this place, was observed in the sea on Monday last, the 27th instant, commencing in the forenoon and ending about sunset. The tide rose and fell in rapid succession more than a dozen times; and one or two boats with cargo which were floating were suddenly found to be high and dry. The wind at the time was blowing half a gale from south-west." And Mr. MAARTENSZ, Sub-Collector, on September the 19th, wrote again:—"I have the honor in continuation of my report (August the 29th, 1883) to inform you that from about the forenoon till sunset of the 27th ultimo, the rise and fall of the sea was observed by me and the people in the wharf to have been (unlike the usual rise and fall of the tides) of very frequent occurrence. The rush of water, both when the sea rose and when it fell, was with some force, giving it a hissing sound; but only once, and that was between 3 and 4 in the afternoon, the sea rose and flowed in beyond the ordinary limit and went down rapidly in a few minutes, so low as to cause a boat, which had put off with a cargo, to get aground high and dry, and another empty boat to capsize at the wharf. The extreme rise and fall of water was not noted at the time, but it must have been about 2 feet above the ordinary level at the tides; and the rise and fall of the sea must have been over twenty times. The wind at the time of the occurrence was blowing rather stiff from south-west, and I could see, with the aid of a glass, that the vessels in the harbour were tossed about in different directions, and the sea about their anchorage was rising in bubbles.

"No noises were heard, nor was any motion of the earth felt here or in the neighbourhood."

Mullaittivu.—Mr. SAMUEL HAUGHTON, Assistant Government Agent, in forwarding some interesting reports by several of his headmen, says:—"There can be no doubt as to the phenomena, reported by the headmen along the coast, having been connected with the recent fatal volcanic disturbance in the Strait of Sunda; Mr. PARKER'S report from Hambantota as to the occurrence of the phenomena so far south, shows that they must have been experienced along the whole eastern coast of Ceylon.

"The reports of the sea-coast Vidahus of Mullaittivu and Kokkulai are of special interest as showing that at sunrise on August the 27th the sky to the east was murky, and the rays of the rising sun obscured by the smoke in the Strait of Sunda.

"The subsidence and return of the sea was noticed all along the coast."

The Police Vidahu, of Mullaittivu, gives the following particulars:—"The sea receded to 16 fathoms distance, and came back to the shore, I am told. This took place only once.

"No one heard any noise here.

"No one saw any cracks in any villages or in the jungle.

"It did not appear that the earth shook here.

"The sun was not bright in the morning at about 6 o'clock, and in the evening from 4 o'clock its rays were green."

Similar reports were sent in by the Police Vidahus of Chemmalai and Kokkulai, in which it is stated that the sea receded and rose again—that sounds as of firing of cannon at Trincomalee were heard, and the Vidahu of Kokkulai states that from

August the 27th to September the 4th the sun and moon were blue-coloured. No cracks or fissures were observed in the ground, and it did not shake.

Trincomalee.—The Chief Clerk of the Royal Engineers Department at this station furnishes a report, from trustworthy information supplied by the head mason who was building a sea-wall at Fort Frederick, from which I quote:—

"The extreme rise (of tide) 4 feet at an average.
„ fall „ „

The number of times the wave appeared to come and go was about thirteen times, of which the sixth, seventh and eighth were those that caused more or less the extreme rise and fall above stated, and the rest were, of course, of a kind not to attract so much the notice of the working men, bearing simply the appearance of a little extraordinary ebb and flow of the sea-water. No noise heard (except what would be heard when a heavy swell of the sea would all of a sudden overflow its shore), nor any motion of the earth felt.

"The exact time was 1.30 p.m. on Monday, August the 27th, 1883.

"The sea receded three times and returned with force in a manner that would attract anyone's notice on the spot; and the ground from the shore to a distance of about 30 feet, no sooner appeared bare and displayed its sediments with fishes struggling about, and a few men (fishers) attempted to try their luck, than the sea returned. In about 5 minutes the sea on that day receded and returned twice.

"A similar change I remember took place at Gun Wharf Pier, when work was going on there, with a slight shock of an earthquake, on December the 31st, 1881, at 8 o'clock a.m."

Batticaloa.—In forwarding reports by the Sub-Collector and Signaller at that station, Mr. Elliott, Acting Government Agent, remarks:—"I was myself absent from Batticaloa on that day, and observed nothing, but on the 27th ultimo, at Kalmunai, Mr. Christie, of the Public Works Department, told me he had heard loud explosions seawards that morning, and that as they sounded like the discharge of heavy artillery he presumed some man-of-war was practising with her big guns out of sight of land, as he could see no ships.

"Captain Walker and Mr. Fielder, at Tumpalancholai and Mahâ Oya, on the Badulla road, at various times on the forenoon of the 27th, were puzzled by hearing noises as if blasting was going on, though there was nothing of the sort for a very considerable distance, if anywhere, in this district.

"Mr. Smith, of the Public Works Department, observed the wave which came up the lake, and rose at his jetty about 2 feet.

"I have not had any intimation of any fissure or crack or any motion of the earth in this district."

The Sub-Collector states that about 6 p.m. on the evening of the 26th he heard "a loud report as if a cannon was discharged down southward," which he and the people near him thought to be thunder; then, on the morning of the 27th, about 7 a.m., he saw the water receding rapidly, and it rose quite suddenly a few minutes afterwards to about 2 feet over ordinary tide, which caused him to remark to the people that what was going on was "the effect of an earthquake somewhere," as a similar phenomenon occurred here on December the 31st, 1881, immediately after the shock of earthquake had been felt.

"The rise and fall of water continued the whole of Monday at intervals of about 10 minutes, the extreme rise and fall being about 2 feet each time; at about 3 p.m. on Monday I heard the noise of water rushing in with some force, and on peeping through the window I observed the water coming foaming near the causeway, and this time the water rose fully 3 feet; the rise and fall continued on Monday night too, and was slightly perceptible till about 10 a.m. on Tuesday.

"At the Bar the rushing of water in and out caused several openings in the sandbank, washing away a small portion of 'Bones' Island' at the mouth of the lake, as reported. People on board the vessels at the anchorage mentioned to me that the vessels were much shaken about and positions changed every quarter or half hour on Sunday night."

Mr. CASINADER, the Signaller at the Flagstaff, states that "about midnight on Sunday, the 26th ultimo, I heard about five or six times a noise similar to that of a cannon being discharged at intervals of 15 minutes, I believe, towards the sea in the east. Very early in the morning I observed the cargo boats that were moored in the lake just opposite to Mr. ATHERTON's bungalow were on the move; but when I noticed it very closely, I found the rise and fall of water at intervals of about 10 minutes; and, in my opinion, the height of the wave in the sea near the Bar rose to about 8 feet about noon on Monday, and in the lake it was about 3 feet high; and on Monday morning, too, about three times I noticed a noise similar to that of the discharge of a cannon in the sea towards the east, and after the highest rise of the water at noon no such noise was heard."

The Acting Government Agent, Eastern Province, gives further interesting particulars obtained by him while on a tour in the southern part of his province in October last, regarding the effects of the tidal wave at Arugam Bay, and of the death of one Moorwoman, whom he believes to have been a "solitary victim out of Java of the recent earthquake."

Arugam Bay is the most easterly bay in which ships can anchor on the east coast of Ceylon. It is situated nearly half-way between Batticaloa and Hambantota, and is directly exposed to any tidal wave from the direction of the Strait of Sunda. From the information given by the Ratamahatmaya of Panama, the wave appears to have been felt with greater force at Arugam Bay than at any other place on the coast from which I have reports.

The Ratamahatmaya says :—"On one day towards the end of July" [this must be a mistake for August] "I was at Panama and heard of an accident at the Bar at Arugam Bay.

"Three Moorwomen, three children, and a man were crossing it about 3 p.m. A big wave came up from the sea over the Bar and washed them inland. Soon after the water returned to the sea. The man said that the water came up to his chest: he is a tall man. These people were tumbling about in the water, but were rescued by people in boats who were fishing in the Kalapuwa (inland estuary). They lost the paddy they were carrying, and one of the women died two days after of her injuries.

"I was further informed by the tindals [masters of vessels] in the ships anchored at the Bay that they felt all of a sudden their vessels go downwards until they plainly saw the ground, and the ships were drawn seawards, and the people on the shore declared the anchors were exposed to sight. After this the wave came in and raised the vessels and overflowed the Bar.

"Up the Navalaru (a stream further south) where the water was heretofore sweet, it has been salt since that time to a distance of at least a mile and a half in a direct line from the sea. In Panama similarly the salt water has come a long way inland."

From the testimony of the tindals and the people on the shore at Arugam Bay it is quite evident that the negative wave or general fall of the sea-level, was the first to affect the shores of Ceylon, and this is corroborated by the more accurate and trustworthy information obtained by Major BAIRD, R.E., from the various self-registering tide-gauges under his charge at the Indian tidal stations, which I shall refer to hereafter.

Hambantota.—This is the most southerly station in Ceylon from which I have received reports, and it completes the circuit of the island. Mr. E. M. D. BYRDE, who was acting Government Agent at the time, reported that on the afternoon of August the 27th, "between the hours of 12 and 2 o'clock, the sea kept on rising several feet above its ordinary level, and receding to a great distance, leaving the jetty almost dry, the water at the extreme end of it not being more than knee-deep.

"About every 20 minutes the sea completely covered the jetty, and rose so high that it washed away one of the old surf-boats that was high and dry near the main road. I sent out a canoe to bring back the boat, but the current was so strong that it was impossible to save it, as it was carried with great rapidity across the bay and then dashed to pieces on the opposite shore.

"The waves did not, as is sometimes the case, break on shore with violence, but the sea rose gradually and similarly receded, and I should say, judging from an examination of the shore this morning, that it must have risen 12 feet, or more, above its ordinary level.

"The fishermen with some difficulty saved the canoe, and with the help of a large gang of prisoners the cargo boat was saved from being carried out to sea.

"The oldest inhabitants here never previously witnessed such an occurrence, and they considered it worthy of notice."

I annex a list of the barometrical observations made on the 26th and 27th of August last at—

		9½ A.M.	3½ P.M.	Mean reading for the Month.		Difference.	
				9½ A.M.	3½ P.M.	9½ A.M.	3½ P.M.
On the 26th	Colombo	29·832	29·721	29·852	29·758	–·020	–·037
	Galle	29·769	29·628	29·843	29·728	–·074	–·100
	Hambantota	29·789	29·675	29·811	29·712	–·022	–·037
	Batticaloa	29·776	29·667	29·800	29·711	–·024	–·044
	Trincomalee	29·597	29·470	29·636	29·537	–·039	–·067
On the 27th	Colombo	29·863	29·749	29·852	29·758	+·011	–·009
	Galle	29·859	29·653	29·843	29·728	+·016	–·075
	Hambantota	29·809	29·689	29·811	29·712	–·002	–·023
	Batticaloa	29·834	29·761	29·800	29·711	+·034	+·050
	Trincomalee	29·611	29·509	29·636	29·537	–·025	–·028

from which you will observe that there was a certain amount of disturbance visibly recorded on these days.

I am, Sir,
Your obedient Servant,
J. STODDART,
Acting Surveyor-General of Ceylon.

G. J. Symons, Esq., *Chairman,*
Krakatoa Committee,
Royal Society,
London.

INDIAN OCEAN.

Eye Observations.

In none of the islands in the Indian Ocean are tide gauges at work. Dr. Meldrum, however, has collected several interesting accounts of the phenomena of rise and fall of the sea at Mauritius, Seychelles, Cargados Garajos and Rodriguez, which are given in full below.

Port Louis, Mauritius.

"Opposite the gasworks, on the southern side of the harbour at Port Louis, Mr. Darney observed that the sea water was going and coming the whole forenoon of August 27th, but at first the movement did not attract much attention. The tide did not rise as usual, and it was difficult to bring the lighters close enough to the shore. At about 13 hrs. 30 mins. the water came with a swirl round the point of the sea wall, and in about a couple of minutes returned with the same speed. This took place several times, the water on one occasion rising 2½ feet. The water was very muddy and agitated, and quantities of jelly fish were thrown on shore. Similar phenomena occurred on the 28th, but to a less extent.

"On the northern side of the Trou Fanfaron, a narrow channel on the north-eastern side of the harbour of Port Louis, Captain Ferrat observed at some time between 13 hrs. 30 mins. and 14 hrs. on the 27th, that the water, which was then unusually low, suddenly rushed in with great violence, rising fully 3 feet above the former level. An alternate ebb and flow then continued till nearly 19 hours, and the intervals in time between high and low water were about 15 minutes. There was no high wave or billow, but strong currents, the estimated velocity of which was about 3 knots in 10 minutes, or 18 knots an hour. Vessels moored near the Dry Docks swayed much, and at about 18 hrs. 30 mins. one of the hawsers of the '*Touareg*,' 10 inches in circumference, parted. Buoys in the neighbourhood were at times seen spinning round like tops. Disturbances were observed on the 28th also, and there were unusual currents even on the 29th.

"Another observer, Mr. Isbester, on the opposite side of the Trou Fanfaron, noticed, at 14 hours on the 27th, that the water around the '*Stella*,' moored within a few yards of him, had a boiling appearance. Suddenly the water receded about 20 feet, leaving some boats partly on dry land. About a quarter of an hour after, the water rushed back and advanced about 6 feet farther inland than where it was at 14 hours. The water then receded, and a series of oscillations took place, lasting till at least 18 hours. The intervals between high and low water were from 15 to 20 minutes, and the range of rise and fall, which at first was about 3 feet, gradually subsided after 16 hours. It was feared that the warps of the '*Stella*' would give way. Similar phenomena were observed on the 28th, and to a small extent on the 29th.

"The Trou Fanfaron is from 200 to 300 feet in width, and about 1,600 in length, running nearly east to west, except near its junction with the main harbour, where it trends to S.W.

"As far as I can ascertain, no disturbances were observed in the central part of the main harbour, which runs nearly S.E. and N.W., and where there is a greater depth of water. Nor does it appear that any were observed outside the harbour.

Tombeau Bay, Mauritius.

"At this bay, which is $3\frac{1}{2}$ miles north of Port Louis, and lies east and west, the sea suddenly receded at about 14 hours on the 27th, and numbers of fish were caught on the exposed beach. Some time after, the water returned with great force. A series of oscillations then took place.

Arsenal and Turtle Bays, Mauritius.

"Mr. COMMINS reports that in the bays, which are $1\frac{1}{2}$ miles north from Tombeau Bay, and which also lie east and west, similar phenomena commenced about noon on the 27th, and lasted till at least 17 hours on that day, the sea rising and falling alternately to the extent of 2 to 3 feet, and the maximum disturbance occurring at about 14 hours. Between the two bays there is a bar. 'Arsenal' being the outer, and 'Turtle' the inner bay. A coaster of 15 tons burthen, while passing at 14 hours from Arsenal to Turtle Bay, stuck on the bar; about 5 minutes after, the sea rushed in from Arsenal Bay and sent the boat flying into Turtle Bay, where, after having made two or three rapid revolutions, it was thrown on the north shore."

Souillac, Mauritius.

"In this harbour, which is on the south coast of Mauritius, several coasters were driven from their anchorage."

The most remarkable thing to be noticed in these reports is the time that is stated to have elapsed between the crests of the long waves.

This is said to be about 30 or 40 minutes, which is much less than the interval given by the nearest tide gauges at the South African ports, but more than the interval of the Ceylon waves. From the position of Port Louis, on the western side of Mauritius, or that farthest removed from Java, it is probable that the waves which passed by the north and south points of the island would arrive separately at the harbour, and that the phenomenon was doubled. The true periodic time would then be from 60 to 80 minutes, which would agree better with the diagrams.

It appears possible, therefore, that the waves here recorded were the long waves felt by the gauges. The Trou Fanfaron being the narrow termination of the funnel-shaped harbour, the effect of the wave would be considerably increased.

The time of the arrival of the first wave, given at about 14 hrs. 15 mins. of the 27th, corresponds to a velocity of 403 miles an hour for the 2,842 miles that separate the 1,000 fathom line off Sunda Strait from the 1,000 fathom line off Port Louis.

This is a higher speed than is given by other observations, but it is to be remarked that the wave selected from the diagrams of self-registering gauges for comparison, as the first of a regular series of higher waves, is generally preceded by other distinct though smaller undulations, and that there is nothing in these eye observations at Port Louis to enable such comparatively small distinctions to be made; and that the time here recorded is that of the first disturbance observed.

Mahé, Seychelles.

"Mr. Estridge, at 16 hours on the 27th, saw the sea rushing in at the rate of about 4 miles an hour, and rising to the extent of 2 feet range. The water returned and receded; and this flow and ebb continued all night and all next day, but the action was quicker and the rise less. From 10 hrs. 15 mins. to 12 hrs. 5 mins. on the 28th, the following observations were made in a channel 23 feet wide and walled on both sides :—

Time.	Water ran.	Rise in inches.	Time.	Water ran.	Rise in inches.
h. m.			h. m.		
10 15	Water ran out . .	—	Noon	Water ran in. . . .	10
10 27	,, in. . . .	10	12 10	,, out . .	—
10 35	,, out . .	—	12 25	,, in. . . .	10
10 40	,, in. . .	10	12 27	,, out . .	—
10 50	,, out .	—	12 45	,, in. . . .	10
11 20	,, in. . .	3	12 50	,, out . .	—
11 25	,, out .	—	12 55	,, in. . . .	10
11 30	,, in. . . .	10	13 05	,, out . .	—
11 40	,, out . .	—			

According to these observations, the mean interval in time between the epochs of high water was 21 minutes. Mr. Estridge says that the action continued throughout the rest of the 28th, and also during a part of the 29th, but less frequently.

The height of the waves is less than those observed at Mauritius, but the journey over the long and shallow Seychelles bank probably killed the wave. These seem to be short waves similar to those observed in Ceylon.

The time here mentioned by Mr. Estridge would give 373 miles an hour for the 2,873 miles, measured from the 1,000 fathom line off Sunda Strait to the outer sounding on the edge of the Seychelles bank of 200 fathoms, which is, however, probably nearly identical with the 1,000 fathoms, as the bank is steep.

Cargados Garajos.

"On August 27th, the '*Evelina,*' Captain Rault, was at anchor on the west-north-west coast of Avocaire Island (one of the St. Brandon islands, which are between 16° 15′ and 16° 57′ S., and 58° 41′ and 59° 26′ E.) in $3\frac{3}{4}$ fathoms, a cable's length off shore. At 15 hours on that day it was observed that the sea suddenly advanced about 20 feet beyond the highest water-mark. As it was then ebb tide this phenomenon appeared very strange. The water soon receded with a rapid motion, and the shoal patches appeared quite dry to a very long distance from the island. Before fifteen minutes had elapsed, the water rose again with the same velocity, coming up to the first mark. It was not a wave, nor a billow, nor a high sea; the water was smooth, except where there were heads of coral, and there only a few wavelets were formed. This to and fro motion lasted up to 19 hours; at first the intervals between high and low water were about 10 minutes, and towards 18 hours, 20 minutes. The current was setting towards E.N.E. of the compass at the rate of ten miles an hour. The sea was not rough outside, nor at the anchorage, nor eight miles N.N.W. from it, where two boats had been fishing from morning till 14 hours. At a quarter of a mile from Avocaire, these boats were caught at 16 hours by the receding tide, and left high and dry for 10 minutes. Similar phenomena occurred between 4 hours and 7 hours on the 28th, but they were less intense; and only four alternate motions of the sea-water were observed."

Here also the periods of the waves are reported as small, from 20 to 40 minutes. The 20 feet, mentioned as being the distance above high water-mark, to which the wave reached, would on the flat sandy shores of the island correspond to perhaps 18 inches or 2 feet of vertical height. The speed calculated from the recorded time of 15 hours would be 370 miles an hour for the 2,662 miles, measured from the 1,000 fathoms off Sunda to the outer sounding of 40 fathoms off Cargados.

Port Mathurin, Rodriguez.

"Serjeant-Major Wallis observed at 13 hrs. 30 mins. on August 27th, a peculiar appearance of the sea-water in the inner harbour. It was then ebb tide, and most of the boats were aground. The sea looked like water boiling heavily in a pot, and the boats which were afloat were swinging in all directions. The disturbance appeared quite suddenly, lasted about half an hour, and ceased as suddenly as it had commenced. At 14 hrs. 20 mins. a similar disturbance began; the tide all of a sudden rose 5 feet 11 inches, with a current of about 10 knots an hour to the westward, floating all boats which had been aground, and tearing them from their moorings. All this happened in a few minutes. The tide then turned with equal force to the eastward, leaving the boats which were close in-shore dry on the beach, and dragging the Government boat (a large decked pinnace) from heavy moorings, and leaving it dry on the reefs. The inner harbour was almost dry. The water in the channel was several feet below the line of reefs; and, owing to the sudden disappearance of the water, the reefs looked like islands rising out of the sea. The tides continued to rise and fall about every half hour, but not so high, or with the same force, as the first tide. By noon on the 29th, the tide was about its usual height, and appeared to be settled. The water was very muddy, and not nearly so salt as sea-water usually is; it was little more than brackish."

Here the wave of 14 hrs. 20 mins. is stated to be the first high one, and is therefore taken for comparison.

The velocity of the wave would, therefore, be 376 miles for the distance of 2,519 miles from the 1,000 fathom line from Sunda Strait to the outer sounding of 200 fathoms on the edge of the steep bank off Rodriguez Island.

The height of 5 feet 11 inches appears precise, but it is so large compared with other records at places at this distance from Krakatoa, that some doubt is permissible as to its correctness. It is not stated how it was measured, and from my personal knowledge of the island and of its flat, fringing reefs, I think that an eye estimation would be liable to considerable error, and I do not fancy that any gauge has been erected since my visit in 1874.

The remark on the brackishness of the water may be taken as evidence of the imagination of the observer.

SOUTH AFRICA AND THE ATLANTIC.

Tidal Diagrams.

Port Alfred.

The first of the more distant tide gauges is that at Port Alfred, in South Africa, 4,624 miles, with an uninterrupted sweep from Krakatoa. This gauge, although placed inside a bar, gives a very good diagram. It is on the scale of 1½ inches to the foot, and 1 inch to the hour. The curve is quite smooth to 7 hrs. on the 27th, when an irregular oscillation commences sharply. This gradually increases to a height of 6 inches, when a distinctly higher wave, of a height of 1 foot 4 inches, is shown at 17 hrs. 10 mins.

Eleven waves of an average interval of 65 minutes can then be traced, although their height is much varied by interference. One cannot be sure that the 17 hrs.

10 mins. wave is that which should be taken as corresponding to the 10 o'clock wave from Krakatoa, but it is apparently the commencement of a fresh series of waves, no period of former waves falling in with it, and I have therefore selected it as the comparison wave. The waves in this series are as follows :—

	h. m.	m.	h. m.	m.	h. m.	m.	h. m.	m.	h. m.	m.	h. m.	m.
Times ..	17 10		18 17		19 22		20 30		21 28		22 44	
Intervals .		67		65		68		58		76		64
Times ..	23 48		1 01		2 03		2 55		4 06		5 05	
Intervals .		73		62		52		71		59		

The double intervals will be :—

h. m.	h. m.	h. m.	h. m.	h. m.
2 12	2 06	2 20	2 15	2 03

The distance, measured from the 1,000 fathom line off Sunda Strait to the 1,000 fathom line off Port Alfred, is 4,550 miles, and the velocity for the 17 hrs. 10 mins. wave will be 388 miles an hour. This corresponds to a depth of 2,245 fathoms, which is probably not far from the truth, though the few soundings which exist on the route, are all over 2,500 fathoms.

The first wave that appears at all, which is very well marked at 7 hrs. 09 mins. on the 27th, can be followed for twelve undulations thus :—

	h. m.	m.	h. m.	m.	h. m.	m.	h. m.	m.	h. m.	m.	h. m.	m.
Times ..	7 09		8 18		9 29		10 40		11 50		13 02	
Intervals .		69		71		71		70		72		69
Times ..	14 11		15 20		16 35		17 45 miss		20 10		21 28	
Intervals .		69		75		70		145		78		

The mean interval is 71 minutes.

The second wave, at 7 hrs. 21 mins., can be followed still further for seventeen undulations, with a mean interval of 77 minutes, as follows :—

	h. m.	m.	h. m.	m.	h. m.	m.	h. m.	m.	h. m.	m.	h. m.	m.
Times ..	7 21		8 38		9 57		11 16		12 35		13 41	
Intervals .		77		79		79		79		66		71
Times ..	14 52		16 07 miss		18 33		19 52		21 11 miss		23 49	
Intervals .		75		146		79		79		158		74
Times ..	1 03		2 23 miss		5 04							
Intervals .		80		161								

The second series of large waves, which commences with one at 18 hrs. 33 mins., can be followed for ten undulations, with a mean interval of 55 minutes, as follows :—

	h. m.		h. m.		h. m.		h. m.		h. m.	
Times ..	18 33		19 23		20 14		21 12		22 08	
		m.		m.		m.		m.		m.
Intervals ..		50		51		58		56		56
Times ..	23 04		24 00 miss		1 52 miss		3 47			
		m.		m.		m.				
Intervals ..		56		112		115				

It will be seen that none of these series but that first given will coincide with the wave at 17 hrs. 10 mins.

The maximum wave is at 23 hours on August 27th, with a height of 1½ feet; and the disturbance continues to 10 hours of the 29th of August.

The complications of waves make this one of the most difficult diagrams to deal with. To what are these earlier waves attributable? This diagram should afford a clue, as the abruptness of the first appearance of the disturbance at 7 hrs. 09 mins. deserves remark, and differs from other diagrams.

But supposing the speed generally deduced from the waves to be approximately correct, the wave that caused this first disturbance must have left Krakatoa at about 23 hrs. 30 mins. on the 26th, local time, at which time there is no record of a wave of any height in the Strait of Sunda. The wave from Krakatoa of 1 hr. 42 mins. of the 27th was recorded faintly on the diagram at Batavia, but this wave was, from the absence of corresponding damage effected on the coast near the volcano, a small one, and it is hardly to be supposed that it could show so sharply on the Port Alfred gauge. Supposing, however, that the 7 hrs. 09 mins. wave is due to the 1 hr. 42 mins. wave, from Krakatoa, it travelled at a rate of 424 miles an hour.

Port Elizabeth.

The Port Elizabeth gauge diagram is not satisfactory, the tracing having been very carelessly made, so that the hour lines are very inaccurate.

The scale is 1 inch to the foot, and 1 inch to the hour.

The gauge is much more exposed than that at Port Alfred, and feels the local waves more.

The diagram at noon, August 26th, begins with continuous oscillations of a few inches, which get slightly larger till 16 hours of the 27th, when two waves of 9 inches height follow one another at 1¼ hours interval.

At 19 hrs. 54 mins. comes an unmistakably large wave of 4 feet range, which I take for the comparison wave.

The disturbance is henceforth well marked with apparently but little interference, but, nevertheless, the intervals of series of waves do not come out well. Six waves follow the comparison wave with periods of 70 minutes. Afterwards they cannot be satisfactorily followed for about 6 hours, when the same period can again be recognised.

Starting with the same wave at 19 hrs. 54 mins., twenty-two waves can be taken with an average period of 2 hrs. 24 mins.

The 19 hrs. 54 mins. series is as follows:—

	h. m.	m.	h. m.	m.	h. m.	m.	h. m.	m.	h. m.	m.	h. m.
Times ..	19 54		21 04		22 14	miss	0 33		1 46		2 57
Intervals..		70		70		139		73		71	

The distance, measured from the 1,000 fathom line off the Strait of Sunda to the 1,000 fathom line off Port Elizabeth, is 4,611 miles, for which the 19 hrs. 54 mins. wave gives a velocity of 320 miles an hour. The speed for Port Alfred, only a few miles eastward, is 388 miles, and therefore these discordant results cannot be considered satisfactory, as Port Elizabeth would give a mean depth of 1,505 fathoms, whereas Port Alfred gives 2,245 fathoms, the track of the waves lying close to one another.

It is not possible to make them agree without straining the evidence, if the comparison wave be selected as being the first of a comparatively regular series; but if the 17 hrs. 52 mins. wave be taken, which might be done by a mere eye selection, the speed of the wave would stand at 371 miles, which would agree better with the adjacent gauges of Port Alfred and Table Bay.

The series of longer periods, starting with the 19 hrs. 54 mins. wave, is as follows:—

	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.
Times ..	19 54		22 12		0 33		3 00		5 25		7 38	
Intervals.		2 18		2 21		2 27		2 25		2 13		2 22
Times ..	10 00		12 20		14 37		17 20		19 42		22 10	
Intervals.		2 20		2 17		2 43		2 22		2 28		2 26
Times ..	0 36		2 50		5 37		8 04		10 22		12 40	
Intervals.		2 14		2 47		2 27		2 18		2 18		2 23
Times ..	15 03		17 28		19 54		22 04					
Intervals.		2 25		2 26		2 10						

Twenty-two waves in all, with a mean period of 2 hrs. 23 mins.

In connection with the disturbance at Port Elizabeth, the following letter from the Captain of one of the large mail steamers then laying in the bay is interesting, as showing that horizontal movement, and that of a rapid character, was taking place at the time the larger waves began to arrive:—

"The '*Hawarden Castle*' was at anchor in Algoa Bay with starboard anchor and 60 fathoms of chain, the anchor being in $6\frac{3}{4}$ fathoms. At about 8 hrs. 30 mins. p.m. on the 27th of August, wind S.E., moderate breeze with a little sea, ship riding head to wind, I observed the ship suddenly swing with head to N.E., bringing wind and sea abeam. My first impression was that our cable had parted, but on going forward I found a heavy strain on the cable caused by the anchor still bearing S.E. from the ship. So heavy was the strain that the friction brake, by which we always ride, and which is powerful enough to part the cable, would not hold. I at once dropped the second anchor, and, on paying out cable, the ship seemed to drift bodily to the N.W., her head still pointing to the N.E. When we had an equal strain on both cables, I had time to remark to the chief officer the strangeness of the occurrence, and while speaking (about 8 hrs. 50 mins. p.m.), the ship again turned round with her head to wind and sea (S.E.). We remained in this position about 8 minutes, when we again swung with head to N.E., but on this occasion more slowly than at first. From this hour till midnight we occasionally headed the wind and sea, but only for a short time, when back we went again, head N.E., with wind and sea abeam. After midnight the wind got very light, and at 3 hours a.m. we were heading the S.E. swell in a calm.

"(Signed) M. P. WEBSTER."

This swinging of the ship means that a current was setting out from the shore.

Now, the time here recorded, 8 hrs. 30 mins. p.m., is just midway between the times of arrival of the first and second crests in the series taken for comparison; and therefore the water would be retreating from the coast and setting seaward.

Table Bay.

This diagram is a good one, but the gauge is evidently influenced by small local waves. The scale is one inch to the foot, and half an inch to the hour.

The first large wave is well marked, though the oscillation before it, is somewhat higher than those preceding.

The greater waves are ushered in by small undulations for some hours; then comes a large wave, of 9 inches range, at 18 hrs. 42 mins. of the 27th, followed by a still larger series of 18 inches. These cannot be followed for more than 12 hours, interferences preventing identification, though the disturbance continues to 19 hours of the 29th of August.

As the 18 hrs. 42 mins. wave falls in very well with the period of the succeeding series, I have taken it for comparison. The series is of 13 waves with a mean period of 62 minutes, and a period for the double waves of 2 hrs. 05 mins.

	h. m.		h. m.		h. m.		h. m.		h. m.		h. m.		h. m.	
Times ..	18 42		19 50		20 53		22 05		23 07		23 58		0 52	
		m.		m.		m.		m.		m.		m.		m.
Intervals ..		68		63		72		62		51		54		68
Times ..	2 00		2 50		3 58		5 00		6 18		7 12			
Intervals ..		50		68		62		78		54				

There is no interference so far, nor any second series. In this respect the diagram greatly differs from those of Port Elizabeth and Port Alfred.

The gauge is situated inside the breakwater, and the wave would, in coming into it, have passed round a complete circle from its original course from Krakatoa.

The tracks followed by the waves to these three South African ports are not identical, though they do not lie far apart, and are sufficiently near to enable us to assume that the mean depth passed over by the separate waves is not far from the same. The Port Alfred wave would give a depth of 2,245 fathoms; that to Port Elizabeth 1,505 fathoms; and the Table Bay wave 2,010 fathoms. These are all for the deep water portion of the tracks, starting from the assumed position of the 1,000 fathom line off the Strait of Sunda, to the same depth off the South African ports. As unfortunately the sounding of the Indian Ocean is very incomplete, it cannot be certainly stated from actual observation what the true mean depth is; but as all the soundings yet obtained on the line of the wave are over 2,500 fathoms, it may be assumed to be in all probability not less than 2,300 fathoms. On this assumption the Port Alfred record agrees fairly with the time calculated from the formula, but the Port Elizabeth and Table Bay waves are too late.

Port Moltke.

At Port Moltke, in the island of South Georgia, a tide gauge was working under the supervision of the German South Polar Expedition.

The scale is 2·42 inches to a foot, and 0·8 inch to an hour.

This position is well open to the sea. The diagram is good, but presents great difficulties.

After small oscillations of 3 inches, a larger wave of 11 inches suddenly appears at 14 hrs. 29 mins. of the 27th. This is followed by three other waves with a mean period of 63 minutes; after which the regularity is lost.

	h. m.		h. m.		h. m.		h. m.
Times	14 29		15 42		16 45		17 40
		m.		m.		m.	
Intervals		73		63		55	

If the first of the series be taken for the comparison wave, it gives an average speed of 487 miles an hour from Krakatoa, which I cannot but think is extremely improbable, corresponding as it does with a depth of 3,500 fathoms.

These undulations diminish after 21 hours, but at 1 hr. 45 mins. on the 28th another wave of 15 inches is recorded, which is followed by others for 20 hours. These waves are complicated and apparently belong to two series of about the same period. The first series of 62 minutes period is—

	h. m.	m.	h. m.	m.	h. m.	m.	h. m.	m.	h. m.	m.	h. m.	m.	h. m.	m.	h. m.
Times ..	1 44		2 46		3 47		4 45		5 48		6 51		8 07		9 07
Intervals ..		62		61		58		63		63		76		60	
Times ..	10 00		11 08		12 03		12 56		13 55		14 53		16 08		
Intervals m. 53		68		55		53		59		58		75			

The double interval is 2 hrs. 3 mins.

The second series of a mean period of 63 minutes is—

	h. m.	m.	h. m.	m.	h. m.	m.	h. m.	m.	h. m.	m.	h. m.	m.	h. m.	m.
Times	2 20		3 25		4 21		5 21		6 18		7 22		8 28	
Intervals		65		56		60		57		64		66		65
Times	9 33		10 41		11 40		12 39		13 44		14 47		15 55	
Intervals		68		59		59		65		63		68		65
Times	17 00		17 55		19 12		20 15							
Intervals		55		77		63								

The double interval is 2 hrs. 6 mins.

If we take the wave at 1 hr. 44 mins. for comparison, the speed—calculated for the distance from the 1,000 fathom line off Sunda Strait to the 100 fathom line off Port Moltke, which is 6,619 miles—is 266 miles an hour. This is apparently as low as the other speed calculated from the first large wave at 14 hrs. 29 mins. of the 27th is high; but the track followed by the wave from Sunda Strait passes in one place south of the Kerguelen Group, where soundings of 160 fathoms have been obtained, and afterwards passes through the pack of Antarctic ice for many miles; so that retardation may not unreasonably be assumed, as the depths are probably not great on this course.

To what cause the earlier waves are to be attributed I am unable to suggest, as the duration of a regular series is not long. The period is not unlike that recognised in so many of the diagrams discussed, and visible in the later series of waves on this gauge.

Altogether the results from this station are not satisfactory. Dr. Neumayer, the Director of the Deutsche Seewarte, Hamburg, has assured me that there is no error in the times used.

Orange Bay, Cape Horn.

The French Meteorological Expedition had an automatic tide gauge at work at Orange Bay. The photographic copies furnished are very small, but I have had them enlarged by photography for purposes of measurement.

This is an interesting diagram, and seems to indicate that two distinct series of waves arrived, one five hours before the other.

The south pole, with its unknown lands, but more or less known icy barriers, intervenes between the Strait of Sunda and Cape Horn. Thus a wave would have to travel round these obstructions, and would pass on both sides, the distance by the west being about 7,520 miles, and by the east about 7,820.

I have come to the conclusion that the earliest waves were those that travelled the greatest distance, for the following reasons :—

A careful examination shows that the eastern wave is unfettered by islands, and that the sea from the few known depths is probably deep. By the other route, on the contrary, the Kerguelen Group is passed, and hereabouts the depths do not exceed 200 fathoms ; also on passing between the Sandwich Land and South Georgia a more or less shallow sea is in all probability travelled over.

The course of the western wave is, for the greater part of the distance, identical with that which reached South Georgia, in which case we have seen that its speed was probably low. If the early waves are taken to be those which passed south of South Georgia, it will appear that they arrived at Orange Bay 1½ hours earlier than at South Georgia, which, seeing that the distance is 850 miles greater, seems impossible.

The gauge was situated in a bay inside a good many islands, which would tend to impede the wave and cause irregularities.

The diagram shows small and irregular disturbance from the commencement, but at 21 hrs. 57 mins. on the 27th there is the first of a short series of four waves with a period of 37 minutes as follows :—

	h. m.		h. m.		h. m.		h. m.
Times	21 57		22 37		23 13		23 47
		m.		m.		m.	
Intervals ..		40		36		34	

Another wave follows, but at 54 minutes interval. The disturbance then dies down, but at 4 hrs. 57 mins. on the 28th there is the first of a second series of eleven waves, with a mean period of 36 minutes, as follows :—

	h. m.		h. m.		h. m.		h. m.		h. m.		h. m.	
Times	4 57		5 32		5 58		6 33		7 06		7 46	
		m.		m.		m.		m.		m.		m.
Intervals ..		35		26		35		33		40		30
Times	8 16		8 57		9 37		10 15		11 00			
Intervals ..		41		40		38		45				

The maximum height of the waves is 7 inches, occurring at the third wave of the first series. The speed of the first series, taken, as I have said, by the eastern route, is 347 miles an hour; of the second, by the western route, 251 miles; which agrees very fairly with that of the South Georgia wave, and tends to show that this conclusion is correct. The diagram shows disturbance till the end, viz., until noon on the 29th, but this is irregular and probably due to local causes.

If these waves are due to Krakatoa, they seem to be again broken up, as the mean period is roughly half of that noted on former diagrams.

For the second and longer series, the double intervals are :—

61 68 70 81 83, or a mean of 73 minutes.

Colon, Isthmus of Panama.

The Colon diagram presents features utterly unlike any other of the gauges under discussion, at a distance from the Strait of Sunda.

Commencing very sharply and distinctly, a negative wave of 5 inches is followed by a positive wave of 13 inches range, the first of a series of sixteen waves with a period of 70 minutes, remarkably regular, with no sign of interference, and gradually dying away in a manner different from all others recorded.

The time of arrival of the first wave is 16 hrs. 30 mins., which gives a speed of 626 miles an hour.

As this corresponds to a mean depth from the Strait of Sunda of over 5,000 fathoms, and, over the greater part of the distance, the depth is known, and is about 2,400 fathoms,—this result may be regarded as out of the question; and the waves which disturbed the Colon gauge must be ascribed to some other cause than Krakatoa.

As the whole of the coast on which Colon lies is subject to rollers of various dimensions, which set in from the Caribbean Sea, with no corresponding local change of wind, it appears that the origin of these waves may be sought in some such direction, with much less improbability than by imagining that an undulation starting from Krakatoa could have travelled to Colon in 18 hours, more especially as the arrival of the wave at Table Bay in 13½ hours necessitates its having travelled the remaining distance, 6,380 miles, in under 5 hours, or at a velocity of over 1,000 miles an hour.

EUROPE.

Socoa.

This harbour, situated in the Bay of Biscay near the boundary of France and Spain, is the nearest place to the northward of the Cape of Good Hope at which an automatic tide gauge was at work. The small photographic reductions of the tidal diagrams have been enlarged three times by photography, and from them the measurements are taken; the same course has been pursued in dealing with the diagrams for Rochefort, Cherbourg, and Havre.

A disturbance, which though small is quite distinct, and fairly regular, appears at 4 hrs. 50 mins. on the 28th, and lasts 10 hours. Seven undulations can be followed with a mean period of 39 minutes.

Times	h. m. 4 50		h. m. 5 25		h. m. 6 13		h. m. 6 45		h. m. 7 27		h. m. 8 04		h. m. 8 42
Intervals ..		m. 35		m. 48		m. 32		m. 42		m. 37		m. 38	

The range does not exceed 3 inches. Taking the first wave at 4 hrs. 50 mins., the speed for a distance of 10,729 miles is 425 miles an hour.

Rochefort.

This gauge is situated 10 miles up the Charente River, but the converging character of the shores of the Basque Roads would tend to magnify the waves.

Four can be traced with a mean interval of 55 minutes as follows, on the 28th of August :—

Times	h. m. 9 40		h. m. 10 35		h. m. 11 28		h. m. 12 25
Intervals		m. 55		m. 53		m. 57	

The range of the third wave is 5 inches. The distance is 10,724 miles, which gives a speed of 414 miles an hour.

Cherbourg.

The disturbance on this diagram is short. The first wave appears at 9 hrs. 20 mins. on the 28th and is followed by four others, of an average range of 2 inches :—

	h. m.	m.	h. m.	m.	h. m.	m.	h. m.	m.	h. m.
Times	9 20		9 59		10 32		11 07		11 44
Intervals ..		39		33		35		37	

The mean period is 36 minutes. The distance from the 1,000 fathom line off the Strait of Sunda to the 1,000 fathom line at the mouth of the English Channel, is 10,780 miles. The 9 hrs. 20 mins. wave gives a speed of 421 miles an hour.

Havre.

This gauge, the farthest up the Channel, and at the greatest distance from Krakatoa of any dealt with, shows very slight disturbance ; but the undulations are fairly regular, though the range does not exceed 1 inch. Period 33 minutes.

Five of these small waves can be traced as follows :—

	h. m.	m.	h. m.	m.	h. m.	m.	h. m.	m.	h. m.
Times.. ..	11 33		12 05		12 40		13 20		13 46
Intervals ..		32		35		40		26	

Taking the distance as 10,780 miles, the speed comes out 422 miles an hour.

Devonport.

The original diagram is on the scale of 0·4 of an inch to the foot, and half an inch to the hour. The gauge is situated a long way up the harbour, but the form of the land tends to enlarge the wave.

A slight oscillation with no regular period begins at 6 hrs. 20 mins. on the 28th, but at 10 hrs. 43 mins. there is a stronger wave of 6 inches range, followed by four others, with a mean period of 65 minutes. The intervals are not, however, very regular :—

	h. m.	m.	h. m.	m.	h. m.	m.	h. m.	m.	h. m.
Times.. ..	10 43		11 35		12 46		2 10		3 05
Intervals ..		52		71		84		55	

I take the 10 hrs. 43 mins. wave as the one for comparison ; and the distance being 11,040 miles, 10,790 of which are in deep water, the speed of the wave comes out at 380 miles an hour.

Portland.

The gauge is on the inner side of Portland Breakwater; to reach which the wave has, from the entrance of the Channel, to pass for 250 miles over depths of less than 100 fathoms.

The diagram here is on the scale of $1\frac{1}{4}$ inches to the foot and 1 inch to the hour. The indications of disturbance are not very conclusive, as no regularity of period is traceable in the small indentations which appear on the 28th of August. They are so small as not to show on the reduced diagram, but they can be seen on the original from 10 hrs. 15 mins. on the 28th for some hours. Taking the earliest appearance at 10 hrs. 15 mins., a speed of 406 miles an hour comes out.

Portsmouth and Dover.

The gauges here show no sign of any disturbance. Seeing that the distance up the English Channel in shallow water is much greater than those already dealt with, and that the disturbances at Havre and Portland are so very slight, this is not surprising.

It cannot be considered that the evidence afforded by any of these six gauges in France and England is conclusive; the disturbance in all of them is too slight. But, looking at them collectively, and seeing the fair accordance of the speed of the waves —which would travel on the same course—the evidence is strongly in favour of the disturbances on these gauges being the effect of one and the same cause, and one which originated at a great distance, or the disturbance would have been of longer continuance.

Against the presumption of their connection with Krakatoa is the high speed at which the wave must have travelled.

In no other case does the depth corresponding to the speed come out otherwise than under the probable truth; but the average velocity of 408 miles given by these six gauges would demand a mean depth of 2,500 fathoms, whereas it is very improbable, from the known soundings, that this quantity is over 2,400 fathoms. On the other hand, the ocean is deep over the whole course, and no checking of the velocity would probably occur from great irregularities of the bottom. Though the wave had to round the Cape of Good Hope, it would do so at a greater distance than the wave which reached Table Bay, and the difference between the speeds—viz., 370 miles to Table Bay and 408 as the average to the edge of the shallow water at the entrance of the English Channel—may be accounted for in this way, and also by the difficulty in tracing the most probable track for the wave in reaching Table Bay.

Nothwithstanding, there is a great discrepancy between the speed from Table Bay to the Channel, and that which the known depth should give by the formula, $V = \sqrt{gh}$. This is the only case in these discussions which affords an opportunity of examining the speed of the wave in different parts of its course. In no other instance do the tracks to different places coincide near enough to allow of a comparison.

Here we have a time of 12½ hours from off the Cape of Good Hope to the Channel, or a speed of 462 miles an hour. This corresponds to a depth of over 3,000 fathoms, whereas the mean depth cannot be over 2,400 at the most, as estimated from the soundings, which are sufficiently numerous to enable this to be stated with confidence.

The tidal wave is 14 hours later in the Channel than at the Cape, which corresponds to a velocity of 412 miles an hour, supposing it to travel from one to the other. Even this gives, by the formula (supposing the wave to be "free"), 2,500 fathoms as a mean depth, which is, as before stated, more than the depth known to exist. It appears, therefore, either that the tidal wave which fills the Channel does not originate in the South Indian Ocean, or that the formula does not give the speed with sufficient exactness.

AUSTRALIA.

Tidal Diagrams and Eye Observations.

To the eastward of the Strait of Sunda the results are very meagre. The few tide gauges in Australia are badly placed, up estuaries, and, with one exception, show very slight and irregular disturbances.

In New Zealand two automatic gauges are at work, but the one at Port Lyttelton, which alone shows much disturbance, is difficult to interpret; and, moreover, the waves it has registered, as well as the reports of eye-witnesses, tend to show that the waves felt in New Zealand had some other point or points of origin than the Strait of Sunda. The disturbances marked on the three gauges at the Sandwich Islands, Alaska, and San Francisco are, as will be seen, also apparently unconnected with Krakatoa.

West Australia.

Here there are no tide gauges; and, as the reports are very crude and vague, not much reliance can be placed upon them.

Cossack, W. Australia.

At 4.30 p.m. on the 27th an extraordinary tide is said to have set in, which rose nearly 5 feet, then went out just as rapidly, the coming in and going out not occupying more than 30 minutes.

This time gives a speed of 423 miles an hour for the 995 miles from the Strait of Sunda to the 190 fathoms off Cossack. This gives a depth of 2,600 fathoms—probably near the truth.

Geraldton, W. Australia.

Here the water is stated to have suddenly risen 6 feet at 8 p.m. on the 27th, and receded so far that boats anchored in 6 feet water were left high and dry. It rose again, but not so high as at first, and continued rising and falling, gradually getting less and less till about noon the next day, when it ceased.

If this time be taken, it would give a speed of only 170 miles an hour from the Strait of Sunda. As at this time it had been dark for two hours, it may be regarded as doubtful whether the wave remarked at 8 o'clock was really the first that reached Geraldton.

From the rapid rise mentioned, it appears that these waves were short ones at both Cossack and Geraldton.

Port Adelaide, S. Australia.

The diagram here shows disturbance, but of so irregular a character that nothing can be founded upon it.

The gauge is placed inside a bar, and some miles up the river.

Williamstown, Victoria.

This bay is situated near the head of Port Phillip. The wave coming from seaward would have to pass over 30 miles of shallow water after getting through the narrows at the entrance, where the tides are very strong. Nevertheless, there is a marked disturbance, which commences at 4 hrs. 30 mins. on the 28th, the range being only 4 inches. This lasts until the 31st, but can be followed as a regular series for only twenty-seven waves. The mean period is 86 minutes, but it varies considerably. There is only one series of waves.

	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.
Times ..	4 40		6 40		8 08		9 35		10 55		12 10	
Intervals		2 00		1 28		1 27		1 20		1 15		1 30

	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.
Times ..	13 40	15 10	16 35	17 50	19 05	20 10
Intervals	1 30	1 25	1 15	1 15	1 05	1 30
Times ..	21 40	23 25	1 05	2 08	3 35	5 00
Intervals	1 45	1 40	1 03	1 27	1 25	1 45
Times ..	6 45	7 45	9 25	11 00	12 00	13 42
Intervals	1 00	1 40	1 35	1 00	1 42	1 23
Times ..	15 05	16 20	17 27	19 25		
Intervals	1 15	1 07	1 58			

The distance, measured from the 1000-fathom line from off the Strait of Sunda to the 130 fathoms off the entrance to Bass Strait is 3,130 miles. The 4 hrs. 40 mins. wave gives a speed of 232 miles an hour, which corresponds to a depth of 800 fathoms. The very few soundings which exist on or near this route are all more than 2,000 fathoms, from which it appears that if the disturbance is connected with Krakatoa the earlier waves must have been so small that they were not recorded on the gauge. The length of the waves precludes the supposition of any local cause or undulations caused by gales. The original diagram is on a scale of 1 inch to the hour.

Sydney, New South Wales.

The record at this port is disturbed, but merely at high water, and no deduction from it appears possible.

On the subject of the Sydney gauge, Mr. H. C. Russell, F.R.S., the Government Astronomer of New South Wales, writes as follows :—

"I should tell you that there is always a little unsteadiness in the Sydney tidal wave at high water, and when the so-called earthquake waves do reach our coast, as they frequently do, they are always greatest about the time of high water.

"Two reasons for the irregular high-water curve have been offered—1st, that, when the tide wave rushes into the complex system of bays forming Sydney Harbour, extending 20 miles in one direction and nearly as much in two others, the water oscillates till it comes to its level ; and 2ndly, and more probably, that the tide wave is divided by New Zealand, and that the two branches arrive on this coast at different times.

"I mention this so that you may make allowance for it in estimating the disturbances recorded at high water.

"Again, the common so-called earthquake waves are fairly regular in interval, from crest to crest, being 25 minutes to 30 minutes, while the best marked of those I send you have a much longer interval, about 45 minutes.

"As soon as we heard of the great eruption at Krakatoa I tried to connect our recorded waves with it, but I found that the velocity for one set was too great, and for the other, too small.

"I did not hear any explosions on August 27th, nor did I hear of anyone who heard such noises at that time."

NEW ZEALAND.

Tidal Diagrams and Eye Observations.

From New Zealand has been received a report from Dr. Hector, F.R.S., accompanied by two tidal diagrams from Port Lyttelton and Dunedin respectively. The report gives the eye observations at different places. From this it appears that at 10 spots on the coast, disturbance was noticed on various dates between the 28th of August and the 1st of September.

I opine that none of these could have originated from the Strait of Sunda, the interval elapsing between the great wave there and the earliest disturbance in New Zealand being far too great to permit the supposition that that wave could have caused them. It was at Port Lyttelton, by Dr. Hector's report, that the disturbance was first noticed.

Port Lyttelton, New Zealand.

The tidal diagram here is on a large scale, 2 inches to the foot and 1 inch to the hour.

The curve is most irregular, and unfortunately at the time Dr. Hector mentions as that at which the disturbance commenced, the chain was entangled.

It is difficult to arrive at any conclusion as to the exact nature of the disturbance, from the absence of diagrams of any days when the movement was normal. On all other days for which diagrams are given, from the 28th of August to the 3rd of September, abnormal motion appears to be taking place.

This is of two kinds; small oscillations with an average of about ten minutes, but with much variation, and larger and very irregular rises and falls.

This is quite unlike the diagrams from other parts to the west of Sunda Strait, where the disturbance may be considered as undoubtedly due to Krakatoa. No regular period can be recognised, and no result is obtainable.

Taking Dr. Hector's statement that the tide ebbed and flowed in an exceptional manner on the evening of the 28th, in conjunction with the broken record of the gauge at that time, 9.45 p.m. may be considered as about the hour when the first wave crest reached the port.

This gives, for the distance from Krakatoa, which, eliminating the shallow water as before, is 4,772 miles from the 1,000 fathoms off Sunda Strait to the 100 fathoms off Port Lyttelton, 159 miles an hour; which corresponds to a depth of 377 fathoms. The true depth is probably not less than 2,300 fathoms.

Dunedin, New Zealand.

This gauge is situated at the head of the long Bay of Otago. It shows a disturbance merely at high water on the 29th at 3 p.m.

Dr. Hector states that at Port Chalmers, four miles lower down the harbour, the water rose and fell irregularly from 11.30 a.m. to 3 p.m. on the 29th.

Taking 11.30 as the earliest time, the wave would have taken 45 hrs. 9 mins. to travel from Krakatoa, which gives a speed of 102 miles an hour for the 4,536 miles from Sunda Strait to the 500 fathoms off Otago. This corresponds to a depth of 150 fathoms, the true depth being probably not less than 2,300 fathoms.

At other places in New Zealand the discrepancy is the same, or even greater.

Thus Dr. Hector states, that at Timaru, "a wave was experienced several times, and a very marked disturbance of the water occurred on the morning of the 29th."

"At Nelson, at 8 p.m. on September the 1st, the tide suddenly rose to some distance above high water-mark, the time for high water not being till after 9 p.m. It fell again about 10 inches, after which it commenced to flow as usual."

"At Thames, at 8.15 a.m. on the 30th of August, the tide, which had previously been ebbing, suddenly turned to flood, running past the lighthouse at Passage like a mill race for about half an hour. It then just as suddenly turned to ebb again, about two hours being wanted to low water. The disturbance was still noticed at the Thames on August the 31st."

"At Auckland a tidal wave was experienced just before the last of the ebb tide on August the 29th. The rise was about 6 feet."

"At Russell, Bay of Islands, and at Mongonui, tidal disturbances were noticed several times in rapid succession on August the 29th."

"On August the 29th earthquake shocks were felt at Brisbane, Rockhampton, and Gladstone in Queensland; also at Patea in Taranaki District, New Zealand."

"At midnight, August 29th—30th, a severe shock was felt at Kiana, New South Wales, about 90 miles south of Sydney."

"On August the 31st a slight shock was felt in South Australia."

Dr. Hector adds, after expressing his opinion that the tidal disturbances were probably due to Krakatoa, and referring to the great earthquake at Arica in 1868:—

"On both occasions we had slight earthquake shocks, produced probably as a secondary result from the inequality of pressure, but similar slight shocks are not infrequent, without being accompanied by tidal disturbances."

It will, I think, be evident that no wave that occurred more than 15 hours (equivalent to a mean depth of 1,300 fathoms) after the eruption at Krakatoa could be, under any hypothesis, attributed to it; whereas the earliest of the disturbances here recorded took place 43 hours, and the latest 116 hours, after the 10 o'clock wave left Krakatoa.

The diversity of times recorded in different places in New Zealand, as well as the brief duration of some of the disturbances, seem to point to some local cause; and it appears that the earthquakes mentioned by Dr. HECTOR are far more likely to have caused them than is the disturbance in the Strait of Sunda on August the 27th. I think that that gentleman will probably agree in this conclusion when he sees the evidence.

THE PACIFIC.

TIDAL DIAGRAMS AND EYE OBSERVATIONS.

We have diagrams from three places in the Pacific, viz., Honolulu; St. Pauls, Kodiak; and Saucelito, near San Francisco.

These all show disturbance, but I do not think that it can be considered to have any distinct connection with the eruption in Sunda Strait, as the speed of the waves deduced is in all cases too high for probability; nor do the differences of times of arrival at the three stations agree with requirements of distance by the several tracks.

At the first glance at a chart it seems that the undulations to these stations might have travelled through the channels of the Eastern Archipelago, and thus have gained the Pacific; but a close investigation will show that this is impossible. The most direct route is *viâ* the Java and Flores Sea and the Molucca passage, and north of New Guinea. We have already seen, however, that the wave travelling to Ujong Pangka—which is on this route—required 10½ hours to traverse the distance, which is 440 miles. Beyond Ujong Pangka is another 200 miles of water of about 40 fathoms before the deeper water of the Flores Sea is reached. This would take another 4 hours, making 14½ hours before the wave was in deep water, and it would still have 5,400 miles to travel before reaching Honolulu. As the first large wave is recorded on the Honolulu diagram only 11 hours after the great wave left Krakatoa, it is obvious that it had not time to proceed by this route.

By the south of Java and *viâ* Torres Straits, we meet with the same difficulty, as, in passing the latter, a distance of over 700 miles of water averaging 30 fathoms in depth, must be traversed.

The waves must therefore have passed south of Tasmania.

Honolulu.

This diagram, on a scale of 1·7 inches to the foot and 0·9 inch to the hour, shows a slight disturbance commencing at 17 hours of the 26th. At 3 hrs. 20 mins. of the 27th a larger disturbance commenced, and lasted, with gradually diminishing height, until September the 1st—a period of five days. This, then, is unlike any of the other diagrams. The maximum wave is about 5 inches. The waves are comparatively short—averaging about 30 minutes. Taking the 3 hrs. 20 mins. wave, we find, for the distance of 8,326 miles, a speed of nearly 800 miles an hour, which requires a depth of 9,500 fathoms, the actual depth being probably not above 2,300 fathoms.

St. Paul's, Kodiak, Alaska.

This diagram, on a scale of 0·9 inch to the foot and 0·75 inch to the hour, shows disturbance from 8 hours of the 27th of August. A larger wave is recorded at 16 hrs. 45 mins., and the disturbance is marked to the end of the 30th. The waves are short and irregular, and the greatest wave is 3 inches. Taking the 16 hrs. 45 mins. wave, the speed for the distance of 10,190 miles comes out 459 miles an hour, which corresponds to a mean depth of 3,100 fathoms. This is too much, but not so startling as the Honolulu result, with which it fails to agree in any way.

Saucelito, San Francisco.

This diagram, on a scale of 1 inch to the foot and 0·45 inch to the hour, shows disturbance from 7 hours on the 27th. The first large wave is at 13 hrs. 20 mins., and is followed for 7 hours by others, when they diminish to a small and irregular oscillation, which lasts until the 30th of August. The 13 hrs. 20 mins. wave is 6 inches in height. Taking this wave, we find for the distance of 10,343 miles a speed of 594 miles an hour, which requires a depth of 5,000 fathoms.

It will be observed that none of these speeds agree, either with one another or with the known facts and probabilities of the depths.

Nor is it possible to localise any one centre from which these disturbances could have simultaneously originated, so that the times of arrival at the three gauges will agree.

An earthquake occurring near the Sandwich Islands or to the south-west of them would give rise to waves which would reach Honolulu and San Francisco at times agreeing with the recorded differences of arrival at these places; but it would be at St. Paul's six hours earlier than the registered time.

Any other assumed position would make the discrepancy greater. Either the waves chosen for comparison on the three diagrams are not identical, nor nearly so, or the disturbances are not due to the same cause.

MAIN CONCLUSIONS.

The main conclusions at which I arrive may be summed up as follows :—

1. That the sea disturbance was probably composed of two descriptions of waves, long waves with periods of over an hour, and shorter but higher waves with irregular and much briefer intervals.
2. That the greatest disturbance, probably formed of both descriptions of waves, originated at Krakatoa at about 10 a.m., local time, on the 27th of August, and was, on the shores of the Strait of Sunda, about 50 feet high.
3. That the long waves of this disturbance, of an original period of about two hours, were alone marked by the automatic gauges.
4. That the speed of the two descriptions of waves was about the same.
5. That the speed of those waves that can be fairly identified, measured by the time of arrival of the first large wave, and counting from the 10 a.m. wave at Krakatoa, was in all cases less than the depth of water would demand according to theory ; assuming that the waves taken for comparison were identical with the 10 o'clock wave from Krakatoa.
6. That the first large wave recorded on the gauges was in most cases preceded by smaller undulations, which did not, however, accord with the period of the larger waves.
7. That to the north and east in the Java Sea the long wave can be traced for 450 miles, but it was at this distance reduced to a very small undulation.
8. That to the west the long wave travelled over great distances; reaching Cape Horn and possibly the English Channel.
9. That the shorter waves reached Ceylon and perhaps Mauritius.
10. That to the south and east of Sunda Strait the propagation of the disturbance was limited ; probably not extending beyond the west coast of Australia.
11. That the disturbances, noted both by eye observers and by the gauges in New Zealand and in the Pacific, had no connection with Krakatoa, but were the results of other seismic action, and were apparently due to more than one centre of movement.

1.

RESULT OF DISCUSSION OF SEISMIC WAVES FROM KRAKATOA, AUGUST 26TH—30TH, 1883.

PLACE. (Automatic Gauges are indicated by Capitals.)	Longitude in Time.	Distance in Geographical Miles.	Commencement of Disturbance.		First Great Wave.					Known Distances and Depths up to the 1,000 fathoms line over which the Wave must travel in approaching the shore.																				Total Miles in known shoal depths.	Time of Wave in known shoal depths by Airy.	Outer depth.	Distances in Mid Ocean.	First Great Wave.		Time of Max. Disturbance after First Great Wave.	Height of Max. Wave in inches.	Duration of Disturbance.	Average depth indicated by Formula $V = \sqrt{gh}$.	Probable mean depth from Charts.	Period of Wave Series in Minutes.	Period of every Second Wave.	PLACE. (Automatic Gauges are indicated by Capitals.)	REMARKS.
			Local Time.	Greenwich Civil Time.	Local Time.	Greenwich Civil Time.	Time from Krakatoa.	Speed in Geographical Miles for whole distance.	Height in inches.	Miles.	Fathoms.	Miles.	Fathoms.	Miles.	Fathoms.	Miles.	Fathoms.	Miles.	Fathoms.	Miles.	Fathoms.	Miles.	Fathoms.	Miles.	Fathoms.	Miles.	Fathoms.	Miles.	Fathoms.					Time in Mid Ocean.	Speed in Mid Ocean.									
	E. h. m.		d. h. m.	d. h. m.	d. h. m.	d. h. m.	h. m.																								h. m.	Fathoms.		h. m.	Miles per hour.			Hours.	Fathoms.			Minutes.		
Krakatoa	7 02	0	26 18 00	26 11 00	27 10 00	27 02 58	0 0	0	?	5	50	45	800	This	is app	roxima	te	..	..	..	..	..	..	..	..	..	..	..	..	50 to west	0 16	1000	..	..	..	..	..	..	..	..	..	..	Krakatoa.	
BATAVIA (Tanjong Priok)	7 07	100	26 20 15	26 13 08	27 12 36	27 05 29	2 30	41	72	10	40	10	30	10	44	15	38	25	25	10	28	5	20	5	15	5	12	5	6	100 to east	2 30	..	0	0 0	0	0	72	36	..	..	122	..	BATAVIA (Tanjong Priok)	
UJONG PANGKA ..	7 30	440	27 17 00	27 9 30	27 21 00	27 13 30	10 32	42	7	10	40	10	30	10	44	15	38	40	25	2	18	120	20	190	29	30	28	12	[illegible]	439 „	10 46	..	0	0 0	0	?	10	48	..	..	..	..	UJONG PANGKA.	
SOURABAYA	7 31	465	27 20 00	27 12 29	27 22 25	27 14 54	11 56	39	7	Be	yond	Ujong	Pang	ka	..	..	..	3	6	4	1¾	18	5	..	..	..	..	..	..	464 „	12 22	..	0	0 0	0	?	7	9	..	..	..	..	SOURABAYA.	
KARANG KLETA ..	7 31	479	27 20 00	27 12 29	27 22 00	27 14 29	11 32	41	10		do.	do.	do.		..	..	..	[illegible]	6	4	1¾	18	5	3	6	11	3½	..	..	478 „	13 13	..	0	0 0	0	?	..	[illegible]	..	..	..	..	KARANG KLETA.	
Padang	6 41	490	..	..	27 13 25	27 06 44	3 46	130	..	1	[illegible]	[illegible]	25	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	9+50=59	mns.mns.mns. 17+16=33	[illegible]	431	3 13	135	?	..	..	270	..	..	..	Padang.	
PORT BLAIR	6 11	1480	27 03 50	26 21 39	27 13 58	27 07 47	4 49	308	7	No	trustw	orthy	inform	ation.	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	?	[illegible]	126	PORT BLAIR.	
Galle	5 21	1680	..	..	27 13 15	27 07 54	4 56	347	48	2	7	15	40	5	500	..	..	..	..	..	..	..	..	..	..	..	..	..	..	22+50=72	25+16=41	1000	1608	4 15	378	..	..	34+?	2120	2400	..	..	Galle	Short waves.
Colombo	5 19	1760	..	..	27 14 30	27 09 11	6 13	284	44	1	4	11	17	2	50	9	500	..	..	..	..	..	..	..	..	..	..	..	..	23+50=73	30+16=46	500	1687	5 27	312	..	..	..	1445	2380	..	..	Colombo	do. do.
NEGAPATAM	5 19	1885	26 23 08	26 17 49	27 14 39	27 09 20	6 22	295	11	6	6	9	20	15	70	..	..	..	..	..	..	..	..	..	..	..	..	..	..	30+50=80	48+16=64	150	1805	5 18	357	1 14	12	34+?	1880	2300	68	132	NEGAPATAM.	
MADRAS	5 21	1935	27 02 30	26 20 57	27 14 33	27 09 12	6 14	304	4	2	8	20	50	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	22+50=72	27+16=43	100	1863	5 31	338	0 0	4	24+?	1700	2300	87	..	MADRAS.	
VIZAGAPATAM ..	5 33	2000	27 00 22	26 18 49	27 15 22	27 09 49	6 51	291	6	1	4	20	24	20	50	..	..	..		..	..	..	..	..	..	..	..	..	..	42+50=92	56+16=72	100	1909	5 39	[illegible]	0 0	[illegible]	33+?	1700	2200	77	154	VIZAGAPATAM.	
FALSE POINT	5 47	2080	27 07 00	27 01 13	27 16 36	27 10 49	7 51	265	8	2	½	5	7	20	15	..	..	..	..	..	..	..	..	..	..	..	..	..	..	27+50=77	64+16=80	[illegible]	2003	6 31	308	1 30	12	10	1400	2150	162	..	FALSE POINT.	
DUBLAT	5 58	2150	27 02 45	26 20 53	27 17 56	27 12 04	9 06	236	8	10	[illegible]	10	5	20	7	10	25	50	70	..	..	..	..	..	..	..	..	..	..	100+50=150	190+16=206	150	2000	5 40	351	0 0	8	7	1820	2100	65	127	DUBLAT.	
DIAMOND HARBOUR .	5 52	2190	..	..	27 20 06	27 14 14	11 16	..	8	40	miles	up Ho	ogly	above	Dubl	at,	ave	rage d	epth	6 fath	oms	..	..	..	..	..	..	..	..	40	h. m. 2 00	Same	Wave.	..	..	..	8	1	..	..	..	..	DIAMOND HARBOUR.	
KIDDERPORE	5 52	2230	..	..	27 22 11	27 16 19	13 21	..	4	40	„	„	„	„	Diam	ond H	r.	„	„	8 „		..	..	..	..	..	..	..	..	40	1 45	Same	Wave.	..	..	..	4	1	..	..	..	..	KIDDERPORE.	
BEYPORE	5 03	2200	Doubt	ful	27 15 49	27 10 46	7 48	285	8	10	10	20	20	10	70	20	500	..	..	..	..	..	..	..	..	..	..	..	..	60+50=110	mns.mns.mns. 68+16=84	1000	2090	6 24	326	12 0	14	31+?	1580	2300	58	116	BEYPORE.	
Trincomalee	5 25	1705	..	..	27 13 30	27 08 05	5 07	334	40?	⅓	13	7	100	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	7+50=57	6+16=22	100?	1650	4 45	347	..	..	?	1770	2300	..	..	Trincomalee	Short waves.
BOMBAY	4 51	2700	..	..	27 18 50	27 13 59	11 01	248	5	18	6	32	25	75	50	42	700	..	..	..	..	..	..	..	..	..	..	..	..	167+50=217	192+16=208	1000?	2482	7 33	331	0 50	7	30	1650	1700	..	..	BOMBAY.	
KARACHI	4 28	3200	27 04 07	26 23 39	27 18 40	27 14 12	11 14	292	10	6	6	[illegible]	30	50	50	30	500	..	..	..	..	..	..	..	..	..	..	..	..	118+50=168	124+16=140	1000?	3032	8 54	340	1 30	15	26+?	1710	2150	69	138	KARACHI.	
ADEN	3 00	3810	..	..	27 17 49	27 14 49	11 51	321	4	4	5	5	10	9	40	30	500	70	800	..	..	..	..	..	..	..	..	..	..	118+50=168	64+16=80	1000	3642	10 31	347	0 30	5	27+?	1770	2150	67	134	ADEN.	
Rodriguez	4 14	2575	..	..	27 14 20	27 10 06	7 08	360	24?	2	13	4	35	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	6+50=56	9+16=25	300	2519	6 43	376	No information.	..	..	2120	?	..	..	Rodriguez.	
Cargados	3 59	2730	..	..	27 15 00	27 11 01	8 03	339	?	6	8	4	13	8	30	..	..	..	..	..	..	..	..	..	..	..	..	..	..	18+50=68	35+16=51	40	2662	7 12	370	do.	..	..	2030	?	..	..	Cargados	Short waves.
Mauritius	3 50	2900	..	..	27 14 15	27 10 25	7 27	388	18?	1	3	[illegible]	20	4	500	..	..	..	..	..	..	..	..	..	..	..	..	..	..	7+50=57	8+16=24	1000	2843	7 03	403	do.	..	..	2430	2600 ?	..	..	Mauritius.	
Seychelles	3 42	2980	..	..	27 16 00	27 12 18	9 20	320	12?	4	12	50	25	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	54+50=104	82+16=98	200	2876	7 42	378	do.	..	..	2120	2300 ?	..	..	Seychelles	Short waves.
PORT ALFRED	1 48	4624	27 07 10	27 05 22	27 17 10	27 15 22	12 24	372	17	19	40	5	500	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	24+50=74	24+16=40	1000	4550	11 44	388	6 00	19	41	2245	2300 ?	64	132	PORT ALFRED.	
PORT ELIZABETH ..	1 42	4690	27 03 30?	27 01 48	27 17 52 27 19 52	27 16 10 27 18 10	13 12 15 12	355 308	16 26	4	10	20	50	5	500	..	..	..	..	..	..	..	..	..	..	..	..	..	..	29+50=79	32+16=48	1000	4611	12 24 14 24	371 320	3 00 1 00	30	65+?	2040 1505	2300 ?	70	143	PORT ELIZABETH.	
TABLE BAY	1 14	5100	..	..	27 18 42	27 17 28	14 30	352	10	2	5	3	15	24	50	20	500	..	..	..	..	..	..	..	..	..	..	..	..	49+50=99	43+16=59	1000	5001	13 31	370	1 00	14	74	2040	2300 ?	62	125	TABLE BAY.	

2.

RESULT OF DISCUSSION OF SEISMIC WAVES FROM KRAKATOA, AUGUST 26TH—30TH, 1883.

PLACE. (Automatic Gauges are indicated by Capitals.)	Longitude in Time.	Distance in Geographical Miles.	Commencement of Disturbance.		First Great Wave.				
			Local Time.	Greenwich Civil Time.	Local Time.	Greenwich Civil Time.	Time from Krakatoa.	Average Speed Geographical Miles for whole distance.	Height above Normal.
	h. m.		d. h. m.	d. h. m.	d. h. m.	d. h. m.	h. m.		Inches
Krakatoa	E. 7 02	0	..	..	27 10 00	27 02 58	0 0	0	..
PORT MOLTKE.. ..	W. 2 27	6676	27 14 0	27 16 27	27 14 28 [illegible] 01 45	27 16 55 28 04 12	13 57 25 14	477 [illegible]	5 7
ORANGE BAY	4 32	by west 7520 by east 7818	27 14 20	27 18 52	28 04 57 27 21 57	28 09 29 28 02 25	30 31 23 31	246 332	5 4
COLON	5 20	11470	..	..	27 16 30	27 21 50	18 52	606	7
SOCOA	0 07	10820	Doubtful.	..	28 04 50	28 04 57	25 59	416	2
ROCHEFORT	0 04	10900	28 07 40	28 07 44	28 09 20	28 09 24	30 26	358	2
DEVONPORT	0 17	11040	28 06 20	28 06 20	..	28 10 45	31 47	347	4
CHERBOURG	0 06	11096	28 09 20	28 09 26	..	28 09 20	30 42	361	1
PORTLAND	0 10	11097	..	..	..	28 10 15	31 17	354	1
HAVRE	0 0	11160	28 11 33	28 11 33	..	28 11 33	32 35	[illegible]	½
PORTSMOUTH	No sign of disturbance.			..	..	..	..	..	..
DOVER	No sign of disturbance.			..	..	..	..	..	..
Cossack	E. 7 50	1190	..	..	27 16 30	27 08 40	5 [illegible]	208	60?
Geraldton	7 38	1480	..	..	27 20 00	27 12 22	9 24	157	72?
PORT ADELAIDE ..	9 14	3015	..	..	..	..	..	..	[illegible]
WILLIAMSTOWN ..	9 39	3324	..	..	28 04 40	27 19 01	16 03	206	2
SYDNEY	10 05	4140	..	..	..	..	..	..	..
Port Chalmers	11 22	4647	29 11 30	29 00 08	[illegible] 11 30	29 00 08	45 10	102	?
PORT LYTTELTON ..	11 31	4862	28 21 45	28 10 14	28 21 45	28 10 14	31 16	165	?
HONOLULU	W. 10 31	8390	26 14 00	27 00 31	27 03 20	27 13 51	10 53	770	..
ST. PAULS (Kodiak) ..	10 08	10320	27 01 30	27 11 38	27 16 45	28 02 53	23 55	431	..
SAUCELITO (S. Francisco).	8 10	10440	27 00 00	27 08 10	27 13 10	27 21 20	18 22	569	7

PLACE. (Automatic Gauges are indicated by Capitals.)	Known Distances and Depths up to the 1,000 fathoms line over which the Wave must travel to approach the shore.														Total Miles in known shoal depths.	Time of Wave in known shoal depths by Airy.	Outer Depth.
	Miles.	Fathoms.	Miles.	Fathoms.	Miles.	Fathoms.	Miles.	Fathoms.	Miles.	Fathoms.	Miles.	Fathoms.	Miles.	Fathoms.	mls. mls. mls.	mns. mns. mns.	Fathoms.
Krakatoa	..	..	..	..	..	..	..	..	..	..	..	..	..	..	50	16 mins. ..	..
PORT MOLTKE.. ..	1	10	12	60	..	..	..	..	..	..	..	..	..	..	7+50=57	7+16=23	100
ORANGE BAY	4	10	25	50	30	100	..	..	..	..	..	..	..	..	59+50=109	63+16=79	200
COLON	[illegible]	7	5	25	[illegible]	70	22	500	..	..	..	..	..	..	33+50=83	25+16=41	1000
SOCOA	¼	1	1	8	5	25	10	50	25	500	..	..	..	..	41+50=91	30+16=46	1000
ROCHEFORT	14	2	12	10	45	25	55	70	..	..	..	..	..	..	126+50=176	197+16=213	1000
DEVONPORT	½	8	2	15	45	40	135	65	15	250	..	..	..	..	198+50=248	184+16=200	1000
CHERBOURG	½	4	[illegible]	7	125	40	135	65	15	250	..	..	..	..	278+50=328	286+16=302	1000
PORTLAND	1½	6	6	13	110	40	135	65	15	250	..	..	..	..	267+50=317	274+16=290	1000
HAVRE	1	2	[illegible]	5	17	15	55	25	125	40	135	65	15	250	356+50=406	410+16=426	1000
PORTSMOUTH	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
DOVER	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Cossack	2	½	4	[illegible]	9	8	25	20	60	45	45	130	..	..	145+50=195	185+16=201	190
Geraldton	1	[illegible]	1	7	3	15	35	30	..	..	..	..	..	..	40+50=90	60+16=76	100
PORT ADELAIDE ..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
WILLIAMSTOWN ..	1	4	9	7	25	12	4	15	105	50	..	..	..	..	144+50=194	138+16=154	130
SYDNEY	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Port Chalmers	5	6	9	15	7	70	40	500	..	..	..	..	..	..	61+50=111	48+16=64	500
PORT LYTTELTON ..	2	[illegible]	8	7	30	45	..	..	..	..	..	..	..	..	40+50=90	66+16=82	49
HONOLULU	1	4	1	20	12	230	..	..	..	..	..	..	..	..	14+50=64	11+16=27	250
ST. PAULS (Kodiak) ..	1	10	4	30	75	50	..	..	..	..	..	..	..	..	80+50=130	88+16=104	100
SAUCELITO (S. Francisco).	1	5	6	10	12	22	10	40	18	500	..	..	..	..	47+50=97	43+16=59	1000

PLACE. (Automatic Gauges are indicated by Capitals.)	Distances in Mid Ocean.	First Great Wave.		Time of Max. Disturbance after First Great Wave.	Height of Max. Wave in inches.	Duration of Disturbance.	Depth indicated by Formula $V=\sqrt{gh}$.	Probable mean depth from Charts.	Period of Wave Series in Minutes.	Period of every Second Wave.	PLACE. (Automatic Gauges are indicated by Capitals.)	REMARKS.
		Time in Mid Ocean.	Speed in Mid Ocean.									
		h. m.	Miles per hour.	h. m.		Hours.				Minutes.		
Krakatoa	..	..	..	..	..	..	..	..	..	..	Krakatoa.	
PORT MOLTKE.. ..	6619	13 34 24 51	487 266	12 00 1 00	7	over 50	3500 1050	?	61	122	PORT MOLTKE.	
ORANGE BAY	7411 7709	29 12 22 12	251 347	1 00	5	,, 45	940 1780	?	36 37	150*	ORANGE BAY ..	* This is the time for every fourth wave.
COLON	11387	18 11	626	..	..	..	5300	2400 ?	..	..	COLON	Not connected with Krakatoa.
SOCOA	10729	25 13	425	12 00	3	26	2660	2300	39	..	SOCOA.	
ROCHEFORT	10724	25 53	414	6 00	3	5	2520	2300	55	..	ROCHEFORT.	
DEVONPORT	10790	28 27	380	..	4	9	2050	2300	64	..	DEVONPORT.	
CHERBOURG	10780	25 40	418	2 00	[illegible]	doubtful	2640	2300	36	..	CHERBOURG.	
PORTLAND	10780	26 27	406	?	1	?	2420	2300	..	..	PORTLAND	Indications very slight.
HAVRE	10780	25 29	422	0 33	1	2½	2640	2300	33	..	HAVRE.	
PORTSMOUTH	..	..	..	..	..	..	..	..	..	..	PORTSMOUTH.	
DOVER	..	..	..	..	..	..	..	..	..	..	DOVER.	
Cossack	995	2 21	423	..	..	?	2640	?	..	..	Cossack	Short waves.
Geraldton	1390	8 08	170	..	..	16	..	?	..	..	Geraldton	Short waves. Probable error.
PORT ADELAIDE ..	..	..	..	..	..	..	..	..	..	..	PORT ADELAIDE ..	Disturbance very slight.
WILLIAMSTOWN ..	3130	13 29	232	..	..	92	800	2400 ?	86	..	WILLIAMSTOWN ..	Not connected with Krakatoa.
SYDNEY	..	..	..	..	..	..	..	..	..	..	SYDNEY	Disturbance very slight.
Port Chalmers	4536	44 06	102	..	..	..	150	2300 ?	..	..	Port Chalmers	Not connected with Krakatoa.
PORT LYTTELTON ..	4772	29 54	159	..	..	..	378	2300 ?	..	..	PORT LYTTELTON..	do. do.
HONOLULU	8326	10 26	797	..	5	132	9400	..	..	..	HONOLULU	do. do.
ST. PAULS (Kodiak) ..	10190	22 11	459	..	3	88	3115	2300 ?	..	..	ST. PAULS (Kodiak)..	do. do.
SAUCELITO (S. Francisco).	10343	17 23	594	..	6	88	5180	..	..	..	SAUCELITO (S. Francisco).	do. do.

12. That from the great differences, caused perhaps by local circumstances, in the appearance of the disturbance on the various tidal diagrams, no precise or close comparison between them can be made, and this doubt of the identification of any particular wave at different places, causes much uncertainty in the result, as far as it relates to the speed of the waves.

It may be remarked that, with regard to conclusion No. 5, Professor MILNE, in his recent work 'On Earthquakes,' finds the same for such other sea waves as have been traced for long distances across the Pacific; though the point of genesis has never been so certainly known as in this instance.

Speed of Free Waves, by Sir George Airy.

Depth in feet	Depth in fathoms.	Geographical miles per hour.	Depth in feet.	Depth in fathoms.	Geographical miles per hour.
3	0·5	5·8	1,998	333	150
6	1	8·2	2,400	400	164
12	2	11·6	3,000	500	184
18	3	14·2	3,600	600	201
30	5	18·4	3,996	666	212
42	7	21·0	4,200	700	217
60	10	26·1	4,800	800	233
78	13	30·0	5,400	900	247
90	15	31·9	6,000	1,000	260
102	17	33·9	7,500	1,250	291
120	20	36 8	9,000	1,500	318
150	25	41·0	10,500	1,750	344
180	30	44·0	12,000	2,000	367
198	33	46·0	13,500	2,250	390
240	40	50·3	15,000	2,500	411
300	50	56·5	16,500	2,750	432
360	60	63·8	18,000	3,000	451
420	70	68·9	19,500	3,250	469
480	80	73·7	21,000	3,500	487
600	100	82·3	22,500	3,750	504
798	133	94·9	24,000	4,000	520
900	150	101	25,500	4,250	536
996	166	106	27,000	4,500	552
1,200	200	116	28,500	4,750	567
1,800	300	142	30,000	5,000	591

List of Tidal Diagrams.

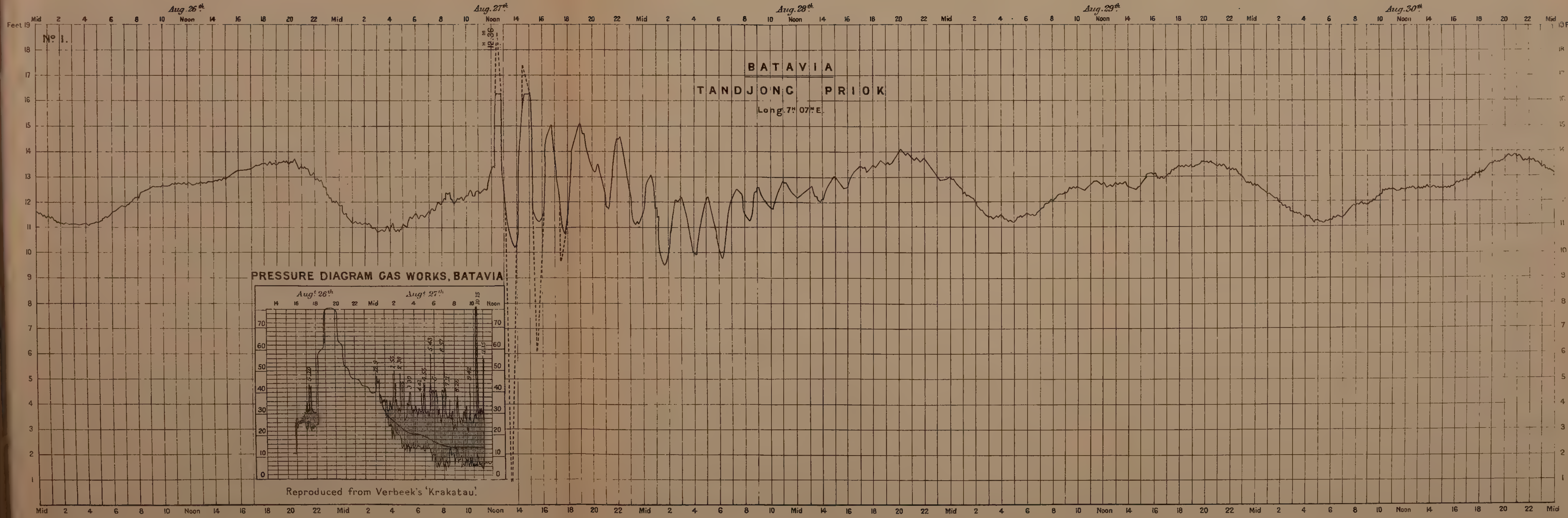
		Plate
1.	Tandjong Priok (Batavia)	XVII.
2.	Ujong Pangka	XVIII.
3.	Ujong Sourabaya	XVIII.
4.	Karang Kleta	XVIII.
5.	Port Blair	XIX.
6.	Negapatam	XIX.
7.	Madras	XIX.
8.	Vizagapatam	XIX.
9.	False Point	XIX.
10.	Dublat	XX.
11.	Diamond Harbour	XX.
12.	Kidderpore (Calcutta)	XX.
13.	Beypore	XXI.
14.	Bombay	XXI.
15.	Kurrachee	XXI.
16.	Aden	XXII.
17.	Port Alfred	XXII.
18.	Port Elizabeth	XXII.
19.	Table Bay	XXII.
20.	Moltke Harbour	XXIII.
21.	Orange Bay	XXIII.
22.	Colon	XXIII.
23.	Socoa	XXIV.
24.	Rochefort	XXV.
25.	Devonport	XXVI.
26.	Cherbourg	XXVII.
27.	Portland	XXVI.
28.	Havre	XXVIII.
29.	Port Adelaide	XXIX.
30.	Williamstown, Port Phillip	XXIX.
31.	Sydney	XXIX.
32.	Lyttelton	XXX.
33.	Honolulu	XXX.
34.	St. Paul, Kodiak	XXXI.
35.	Saucelito, San Francisco	XXXI.

Illustrative Charts.

		Plate
1.	Sunda Strait, before eruption	XXXII.
2.	Sunda Strait, after eruption	XXXIII.
3.	Java Sea	XXXIV.
4.	World	XXXV.

W. J. L. Wharton.

LOCAL CIVIL TIME



BATAVIA

TANDJONG PRIOK

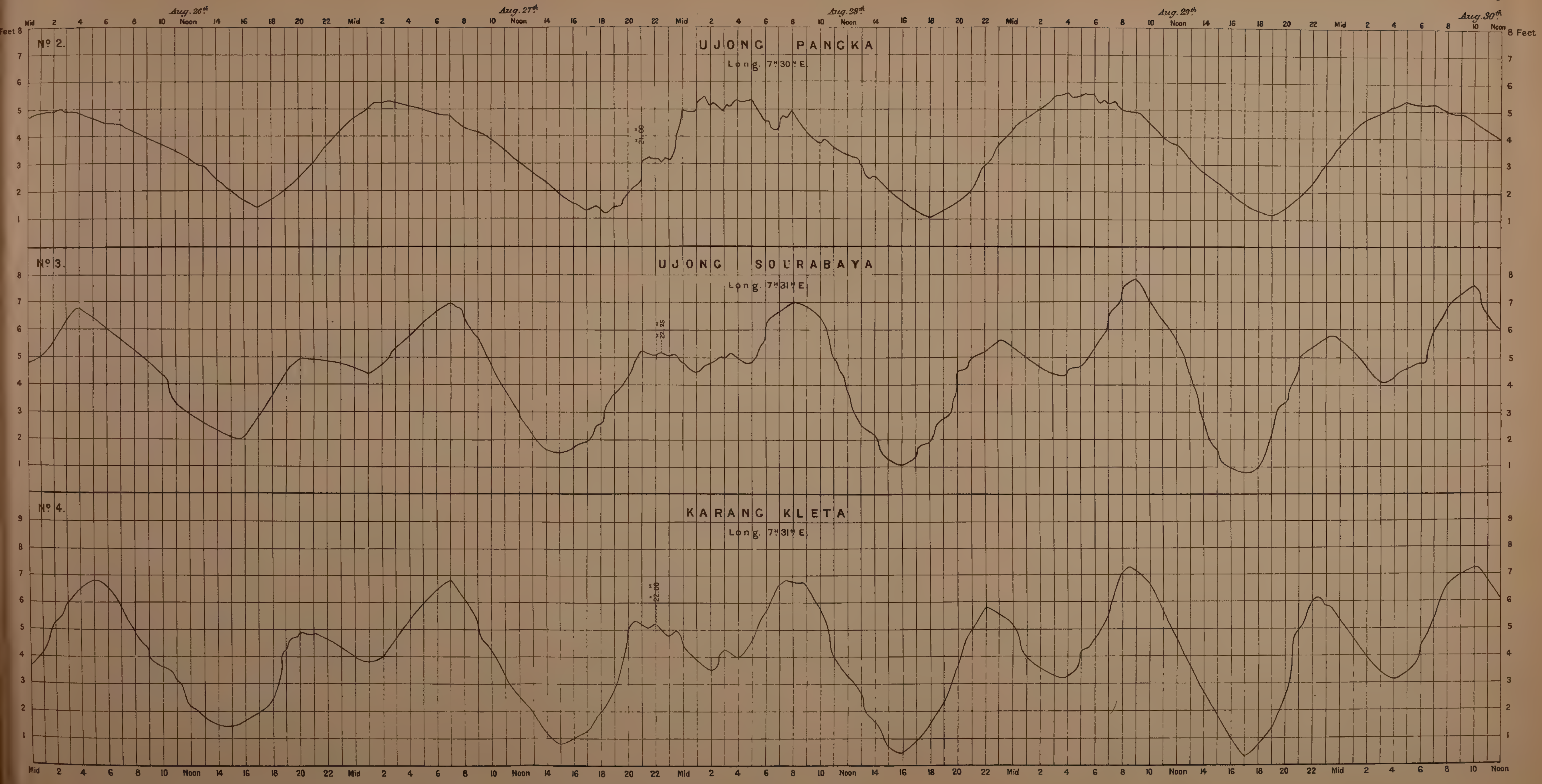
Long. 7h 07m E.

PRESSURE DIAGRAM GAS WORKS, BATAVIA

Reproduced from Verbeek's 'Krakatau'.

Malby & Sons, Lith.

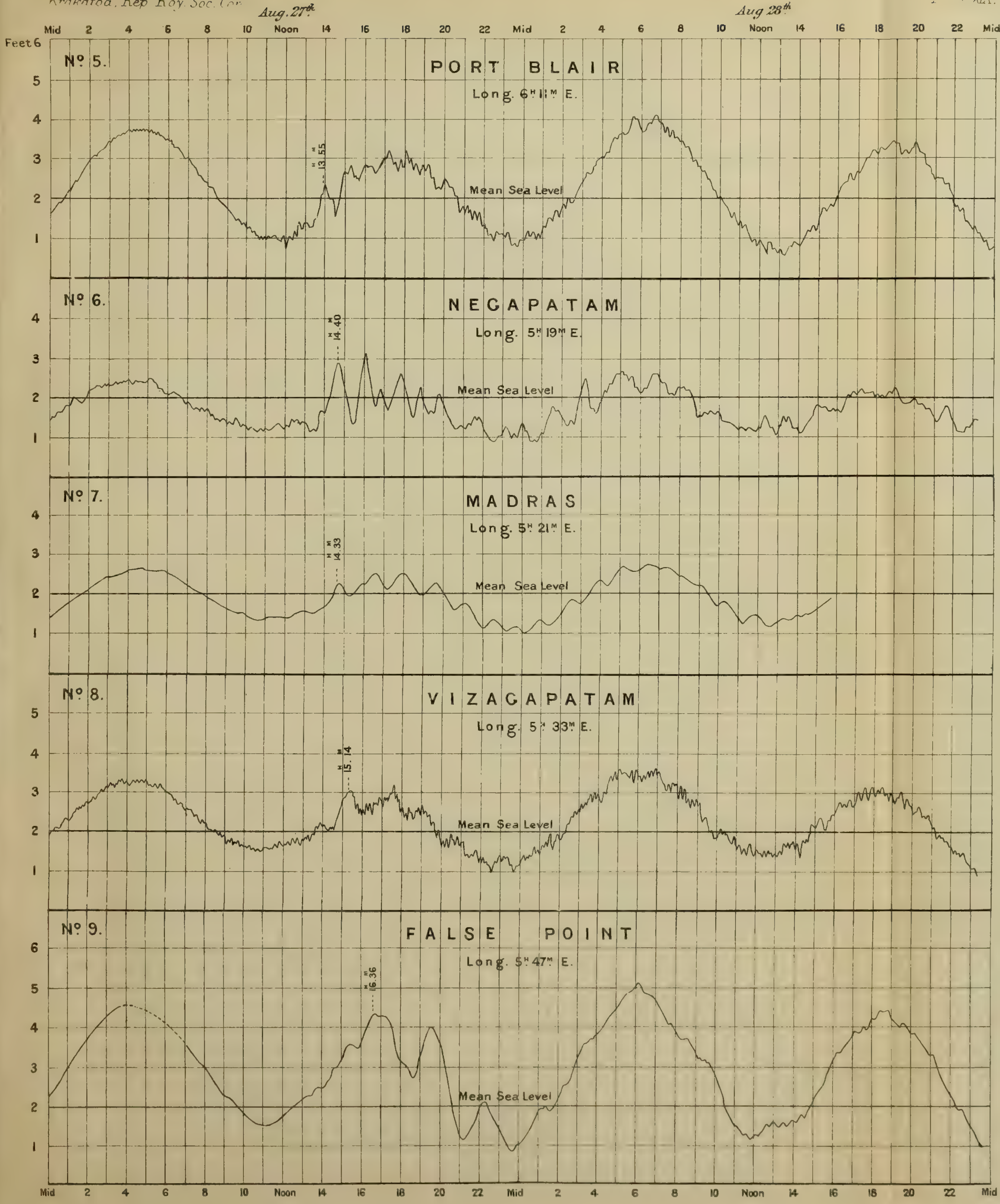
LOCAL CIVIL TIME



Malby & Sons, Lith.

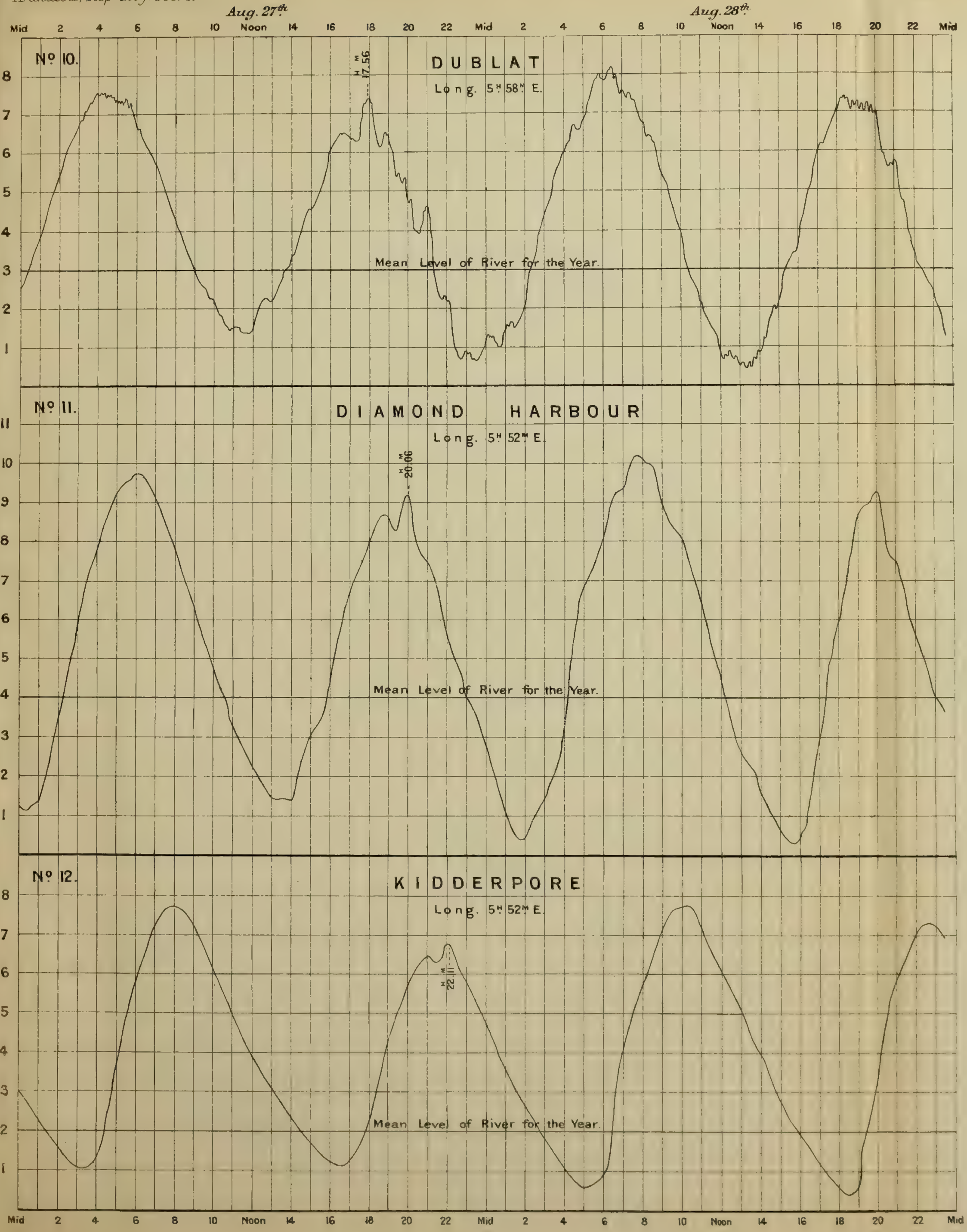
LOCAL CIVIL TIME

Krakatoa. Rep Roy. Soc. Com. *Plate XIX.*



Malby & Sons Lith.

LOCAL CIVIL TIME



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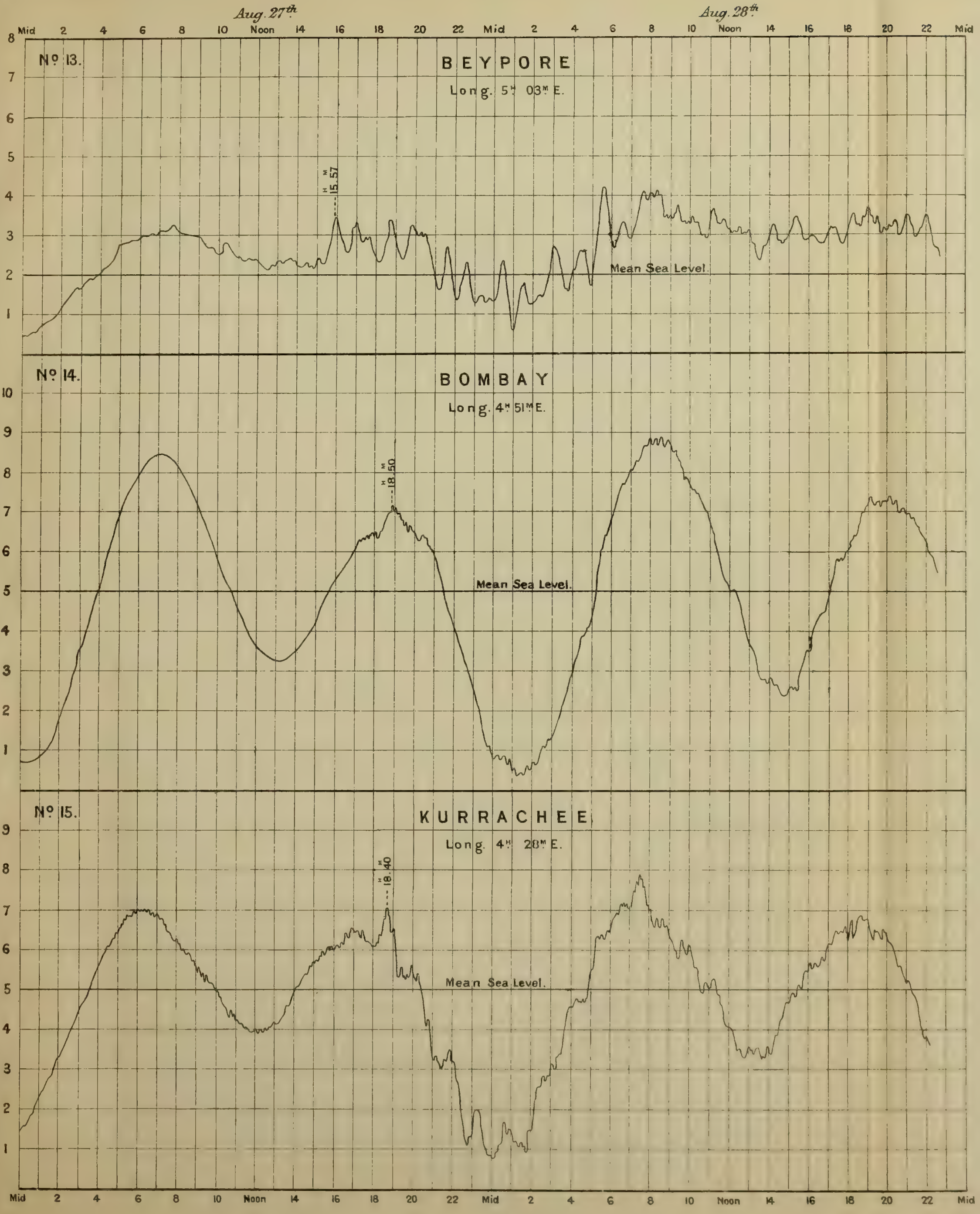

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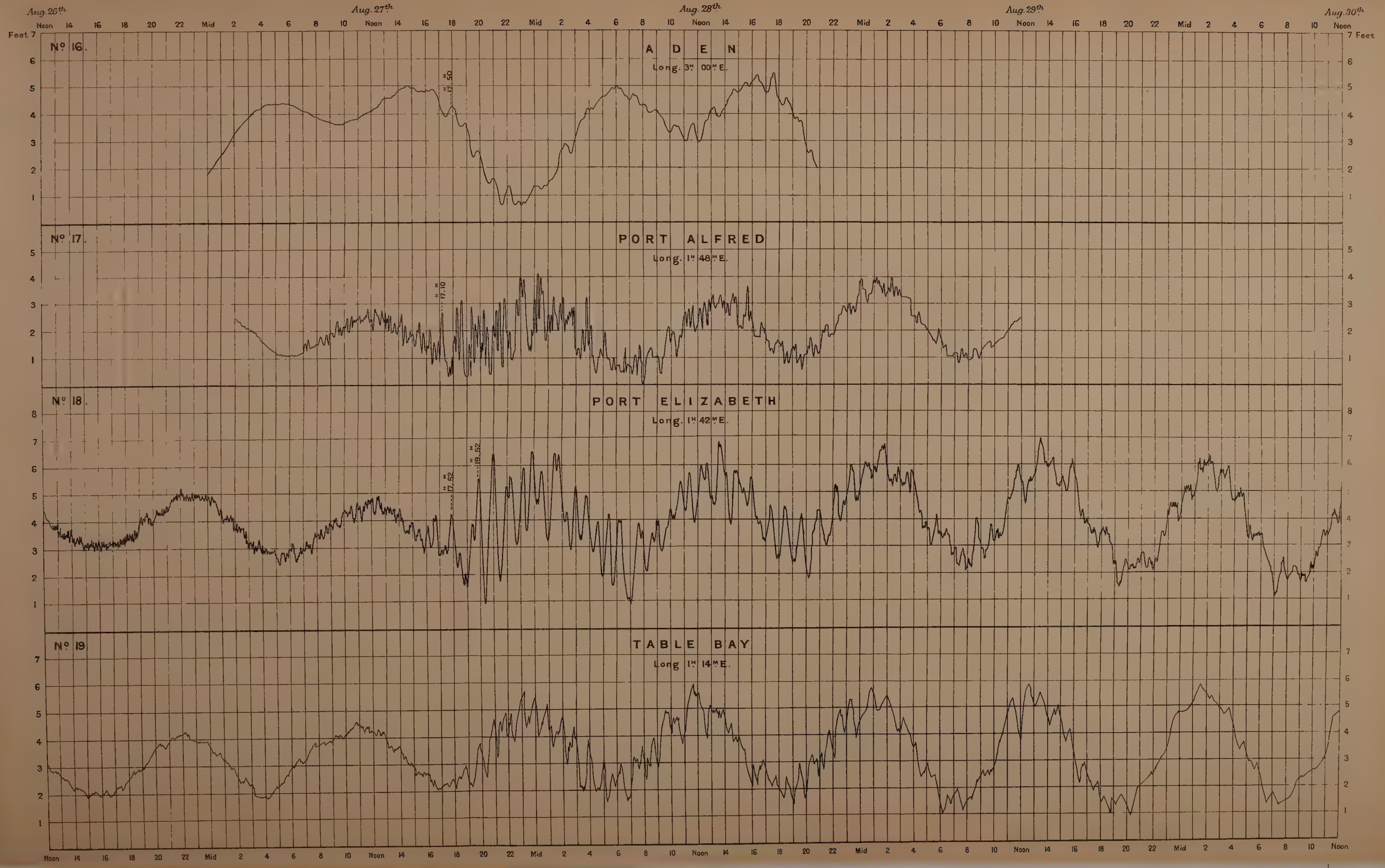
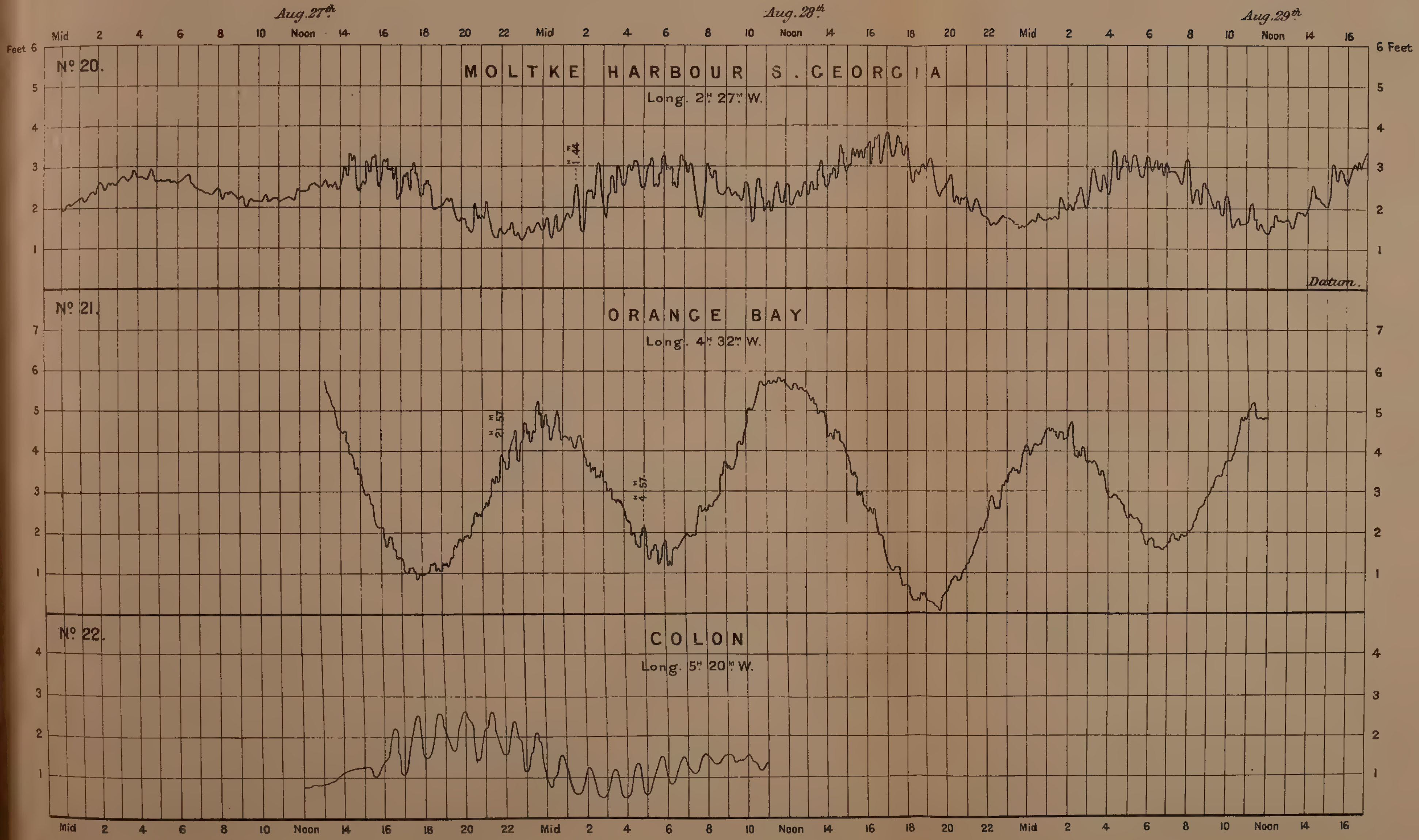


LOCAL CIVIL TIME



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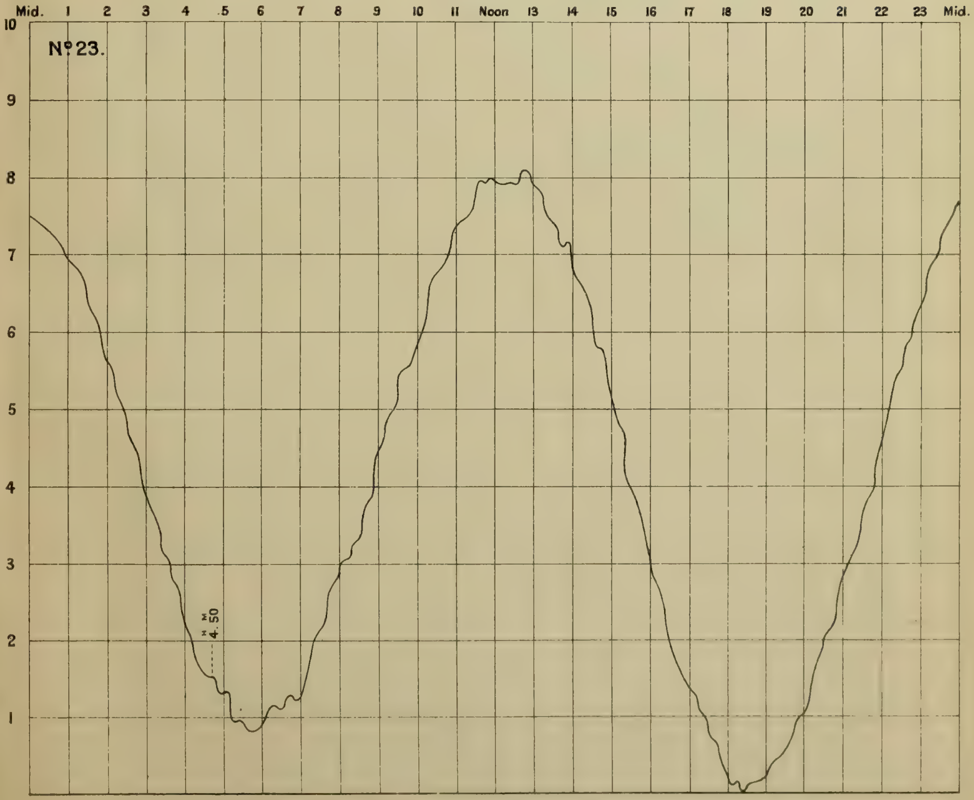
LOCAL CIVIL TIME

SOCOA

Long. 0h 07m W.

August 28th.



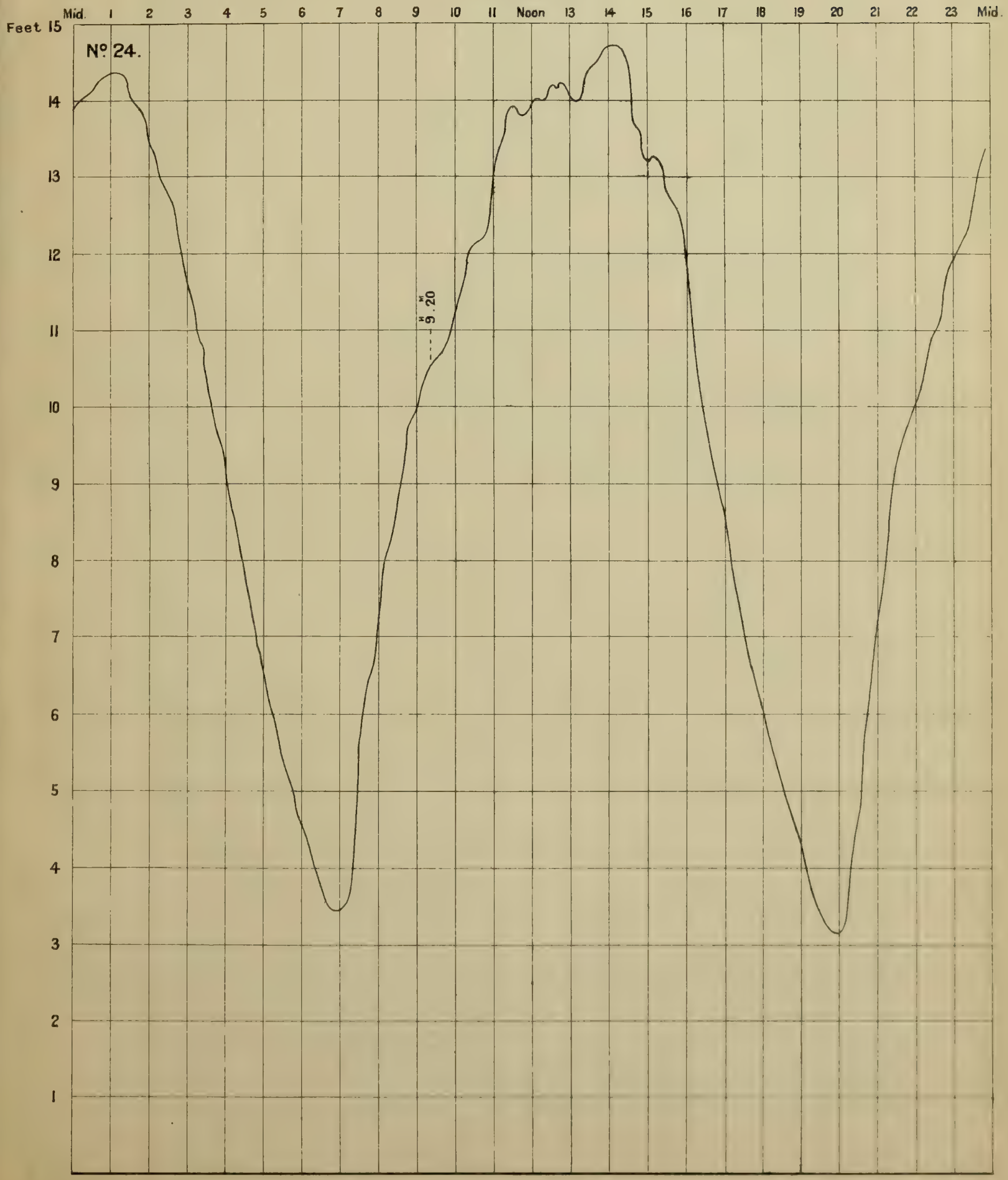
Malby & Sons, Lith.

LOCAL CIVIL TIME

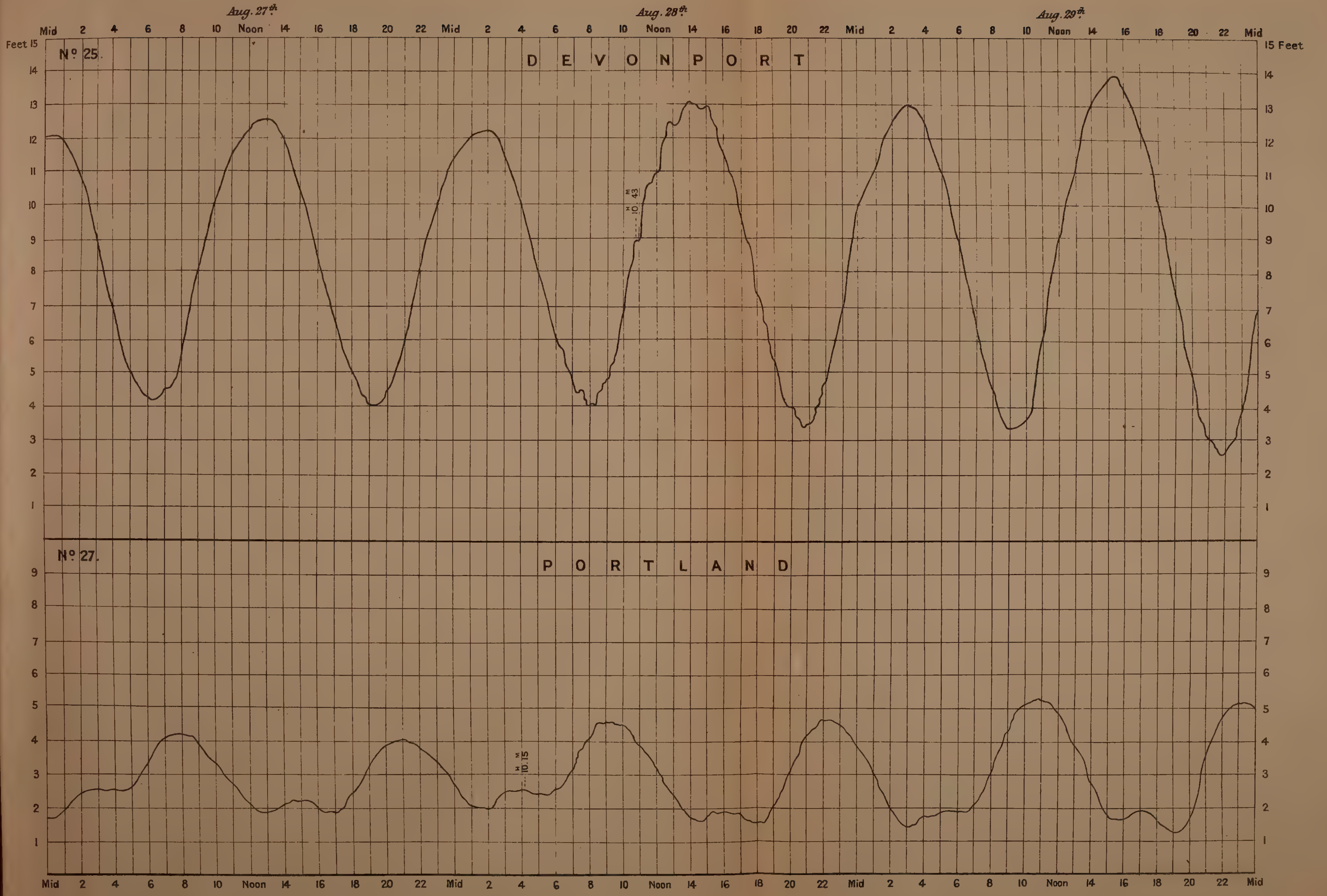
ROCHEFORT

Long. 0h 04m W.

August 28th.



GREENWICH CIVIL TIME



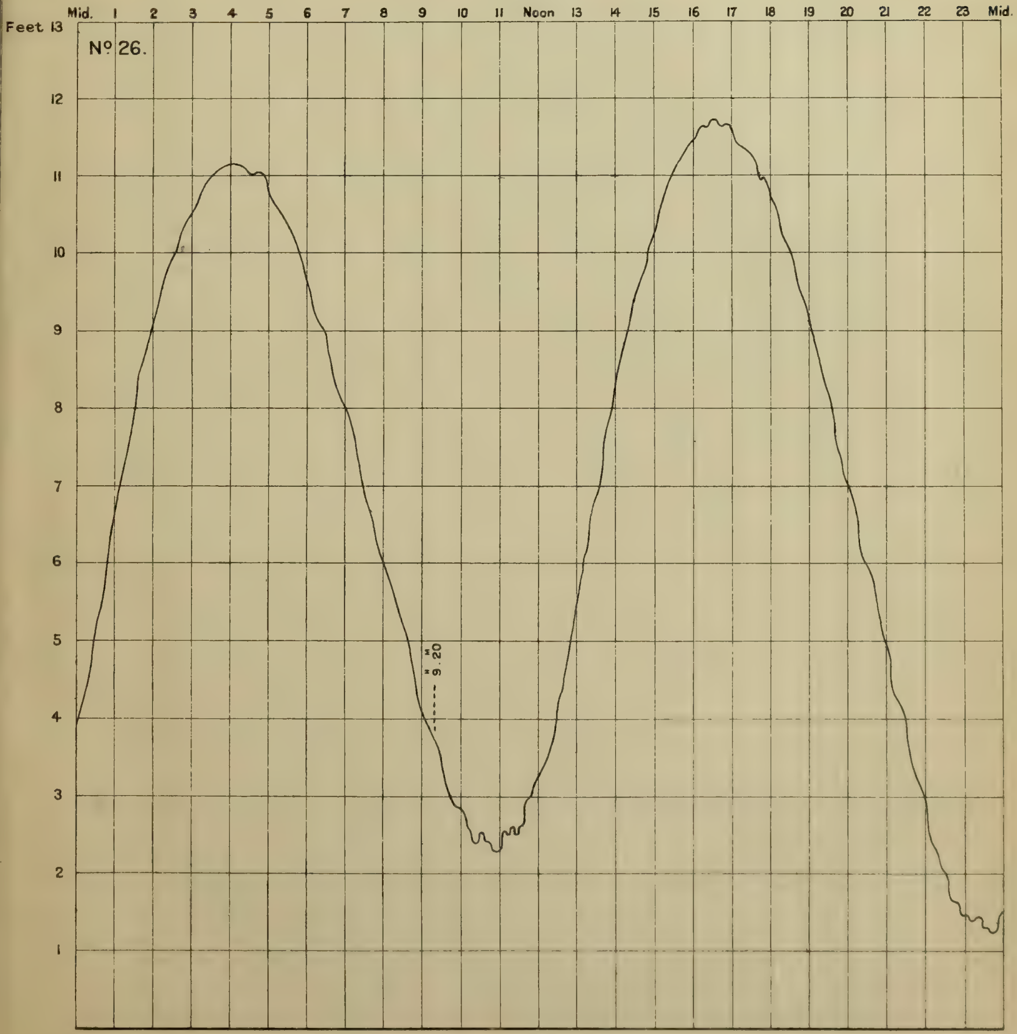
Malby & Sons, Lith.

LOCAL CIVIL TIME

CHERBOURG

Long. $0^h\ 06^m$ W.

August 28th.



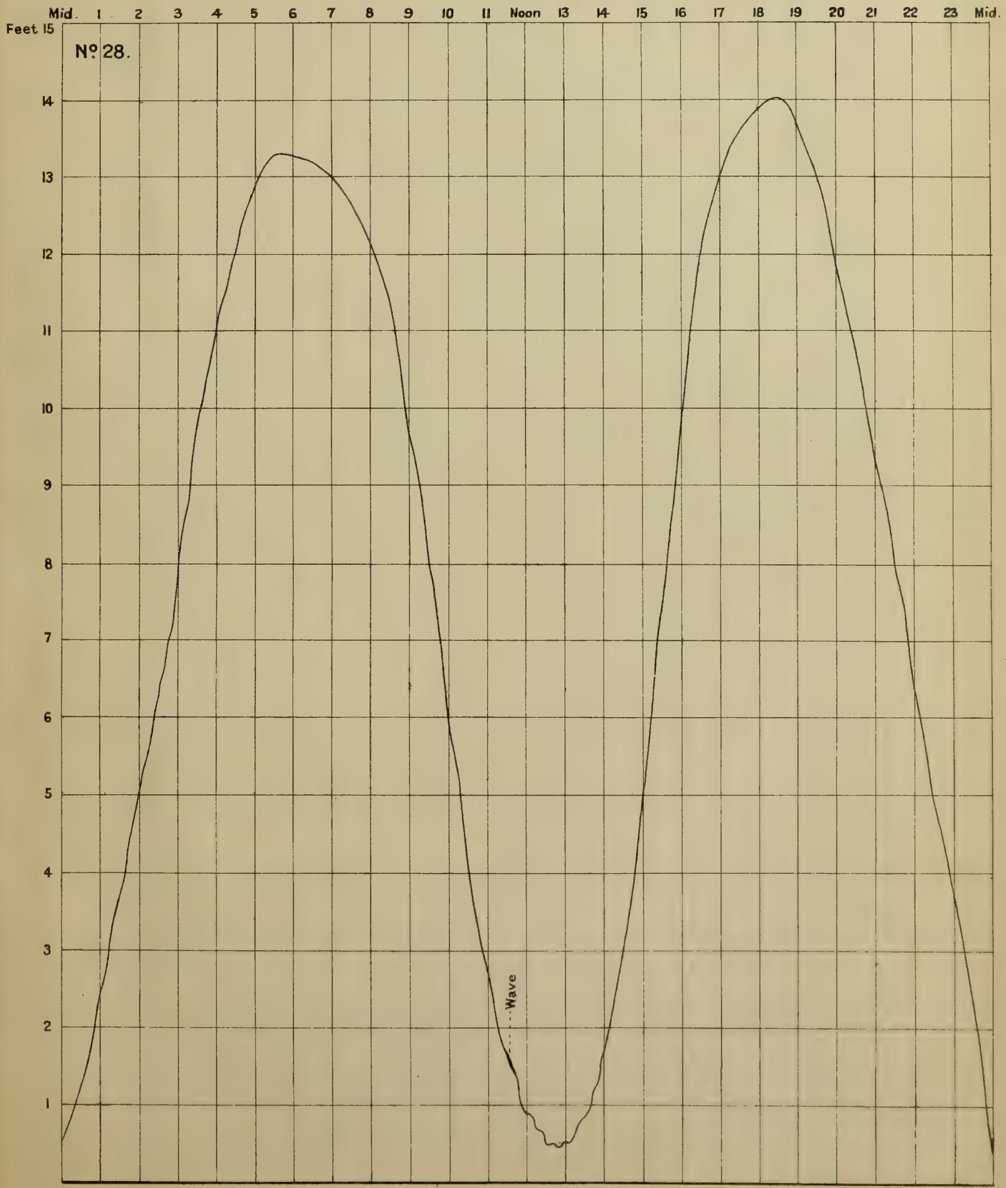
Malby & Sons, Lith.

LOCAL CIVIL TIME

HAVRE

Long. 0h 0m E.

August 28th.



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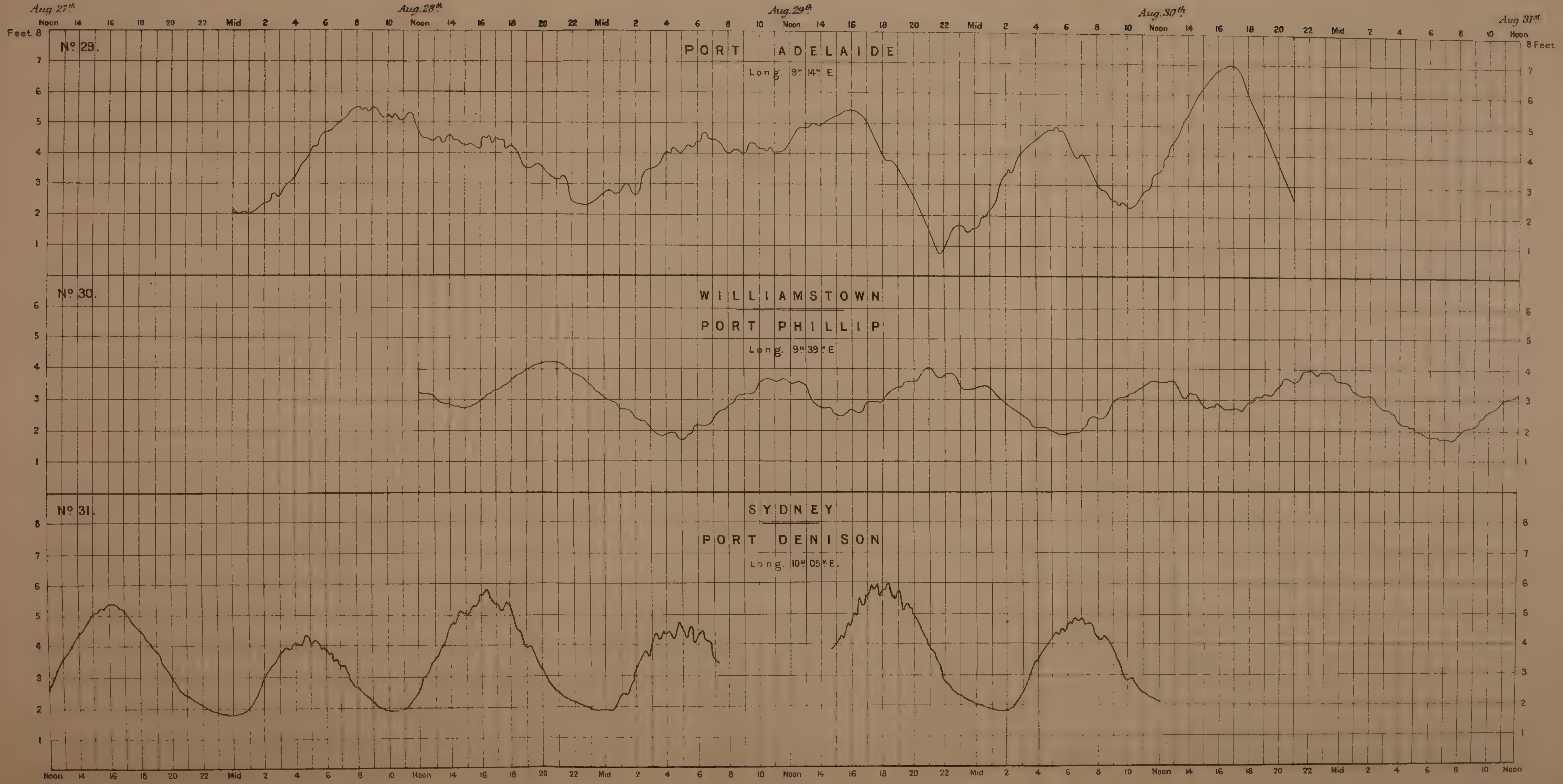

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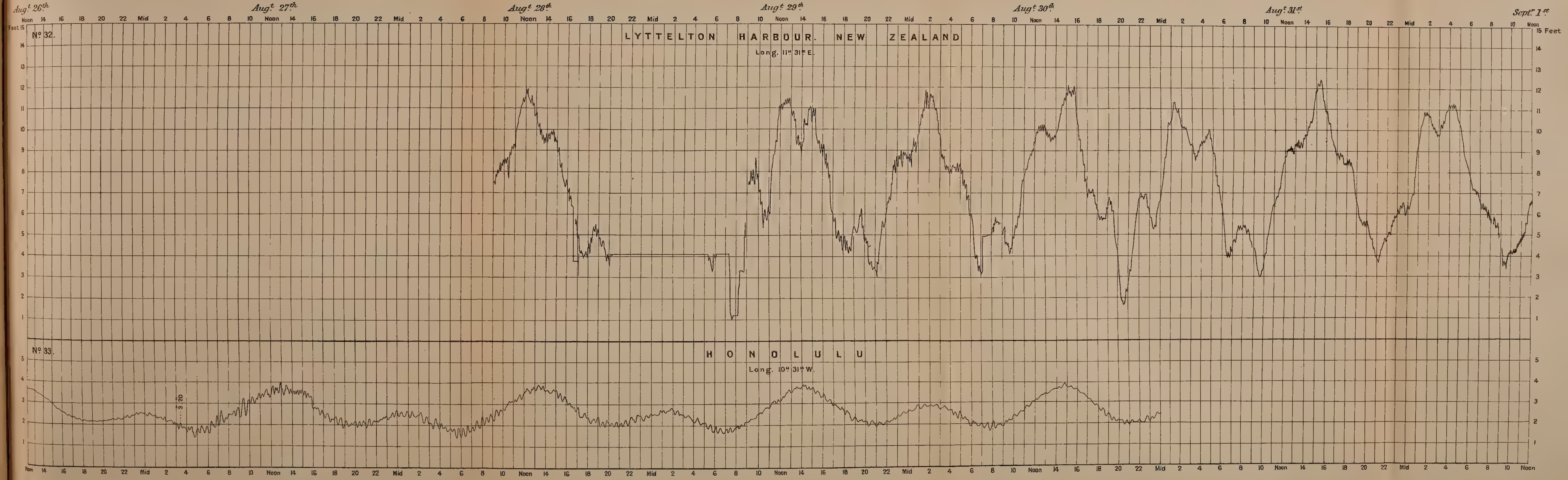

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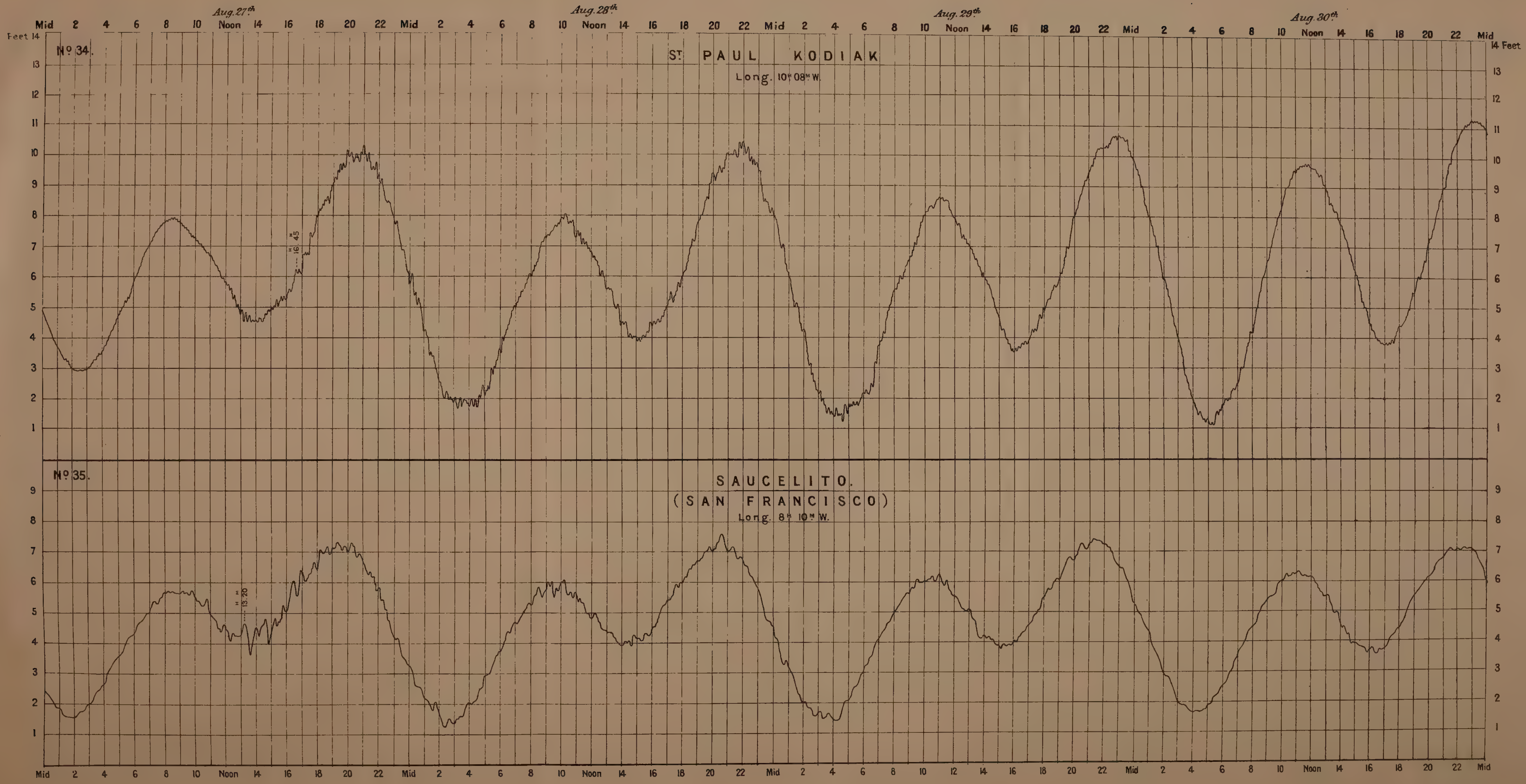

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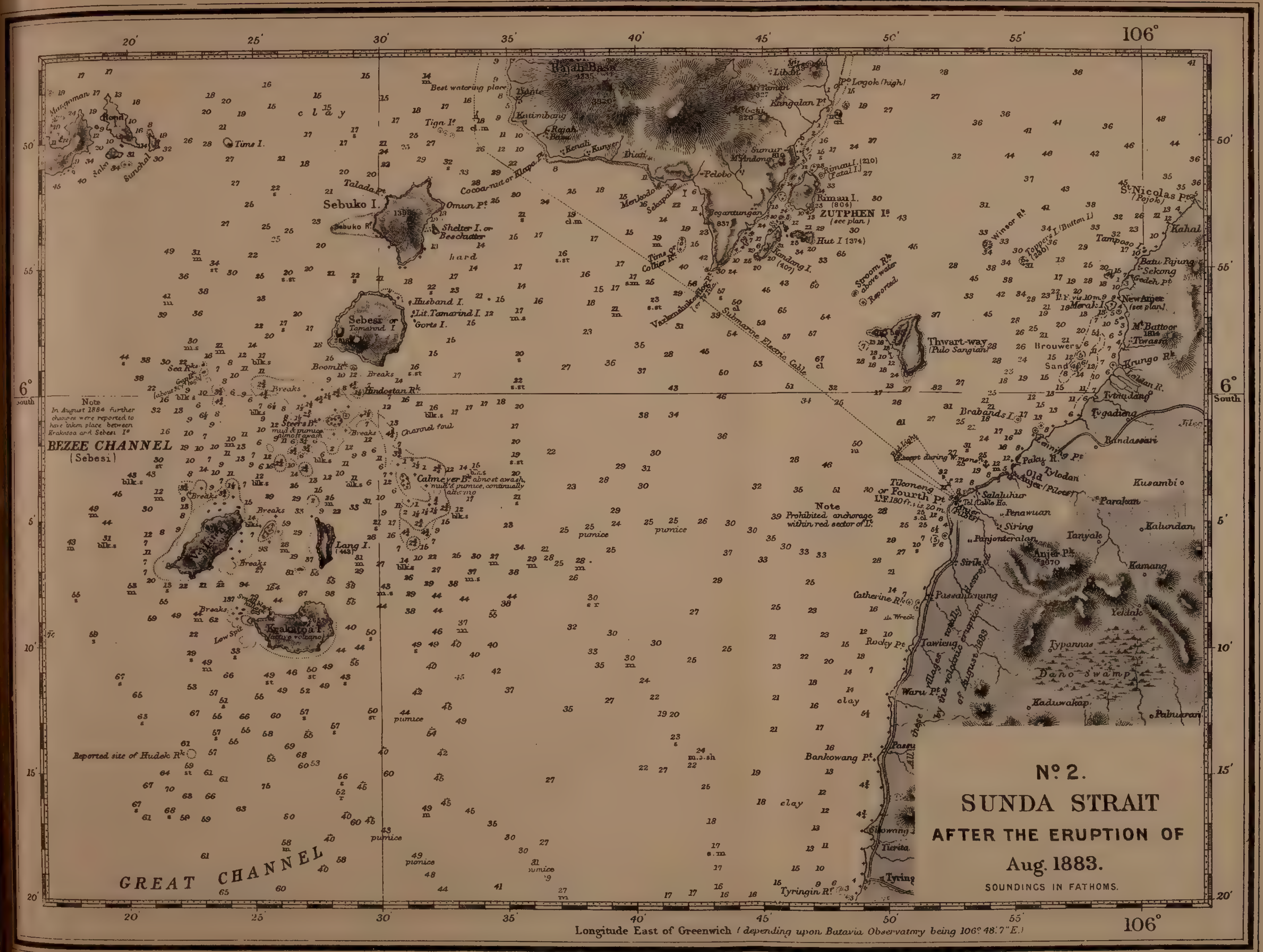
Nº I.

SUNDA STRAIT

BEFORE THE ERUPTION OF Aug. 1883.

SOUNDINGS IN FATHOMS.

Longitude East of Greenwich (*depending upon Batavia Observatory being 106° 48′ 7″ E.*)



No. 2.

SUNDA STRAIT

AFTER THE ERUPTION OF

Aug. 1883.

SOUNDINGS IN FATHOMS.

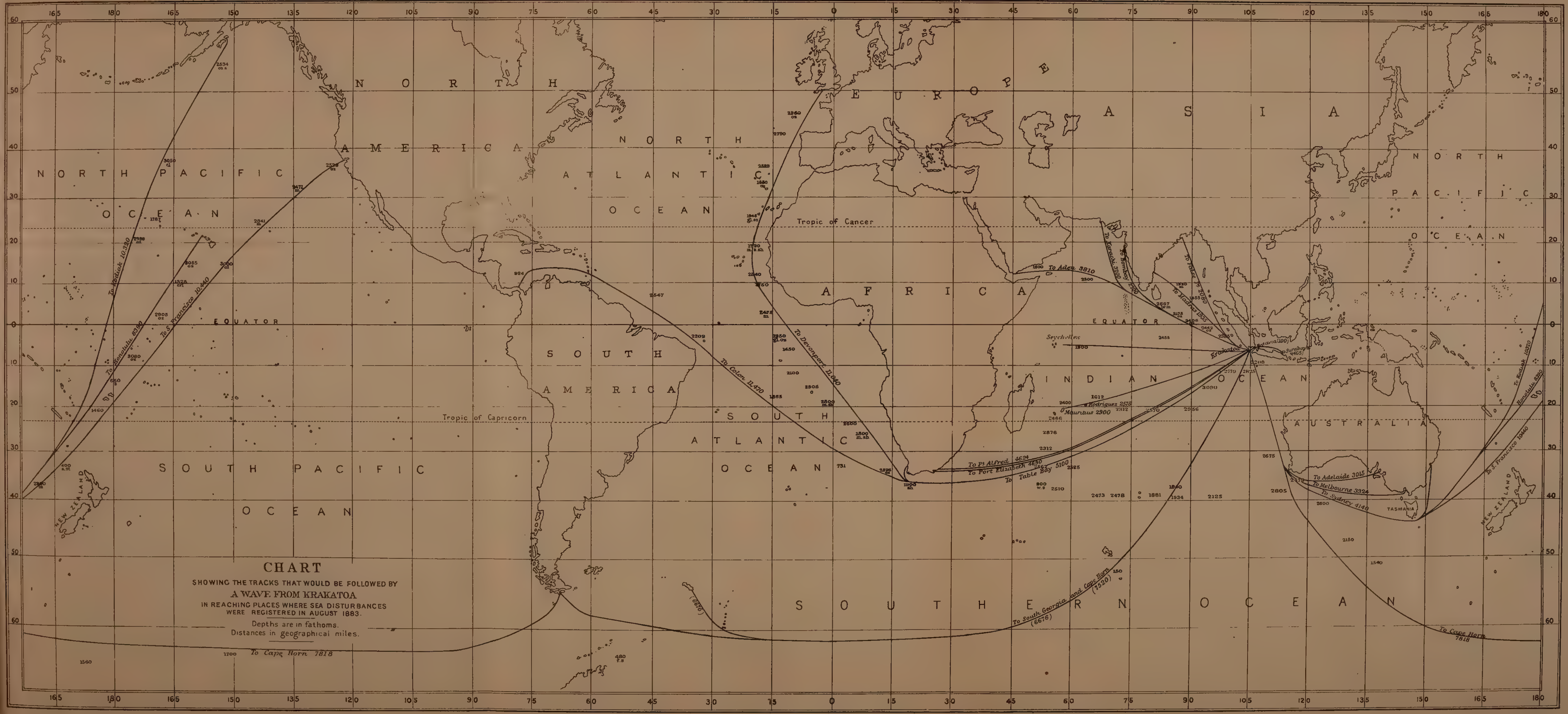
Malby & Sons, Lith.

JAVA SEA

showing places where the "seismic" wave of the 27th August 1883 was recorded.

SOUNDINGS IN FATHOMS.

Maltby & Sons Ltd



CHART

SHOWING THE TRACKS THAT WOULD BE FOLLOWED BY

A WAVE FROM KRAKATOA

IN REACHING PLACES WHERE SEA DISTURBANCES WERE REGISTERED IN AUGUST 1883.

Depths are in fathoms.

Distances in geographical miles.

PART IV.

ON THE UNUSUAL OPTICAL PHENOMENA OF THE ATMOSPHERE, 1883-1886, INCLUDING TWILIGHT EFFECTS, CORONAL APPEARANCES, SKY HAZE, COLOURED SUNS, MOONS, &c.

By the Hon. F. A. Rollo Russell *and Mr.* E. Douglas Archibald.*

As this part is necessarily very long, we have found it convenient to divide it into sections and sub-sections; though even thereby a fresh difficulty and some repetition are introduced in consequence of the intimate relation subsisting between the various phenomena. We have, however, finally decided upon the following arrangement :—

Section I.—

(A.) Descriptions of the unusual twilight glows in various parts of the world, in 1883–4.

(B.) Proximate physical cause of the unusual twilight glows.

(C.) The blue, green, and other coloured appearances of the sun and moon.

(D.) The sky haze and some of its effects.

(E.) The large corona round the sun and moon, generally known as "Bishop's Ring."

Section II.—General list of dates of first appearance of all the optical phenomena (with maps representing the distribution).

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* The authorship of the sections and sub-sections is indicated by the name appended to each.

Section III.—

(A.) General geographical distribution of all the optical phenomena in space and time; including also velocity of translation of "smoke stream."

(B.) Connection between the propagation of the sky haze and its accompanying optical phenomena and the general circulation of the atmosphere.

(C.) Spread of the phenomena round the world.

Section IV.—Diurnal and secular variation in the duration and brilliancy of the twilight glows, and the height above the earth of the stratum which caused them.

Section V.—Previous analogous glow phenomena, and corresponding eruptions.

Section VI.—Individual opinions expressed, and hypotheses suggested, to account for the abnormal optical phenomena.

Section VII.—General analysis of the connection between the unusual meteorological phenomena of 1883-86, and the eruptions of Krakatoa in May and August, 1883.

PART IV.—SECTION I. (A).

DESCRIPTIONS OF THE UNUSUAL TWILIGHT GLOWS IN VARIOUS PARTS OF THE WORLD IN 1883–84.

By the Hon. ROLLO RUSSELL.

INTRODUCTION.

THE COMMITTEE has been favoured with voluminous correspondence, all which has received careful consideration, and much has been utilized in various sections of this Part, but only a small portion could be quoted *in extenso.* The following descriptions have been selected, partly from it and partly from printed sources, as indicative of the nature of the phenomena in various countries, and are arranged chronologically.

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The Rev. S. E. BISHOP,* says :—

"I would note three peculiarities of the phenomenon, distinguishing it from ordinary sunset reflections, and unlike anything I remember to have observed before :—

"(1). It appears to be a reflection from no cloud or stratum of vapour whatever.

"(2). The peculiar lurid glow, as of a distant conflagration, totally unlike our common sunsets.

"(3). The very late hour to which the light was observable—long past the usual hour of total cessation of twilight.

"To this may be added—

"(4). That the centre of brilliancy was more or less to the south of west."

In a subsequent communication, Mr. BISHOP tells us that the after-glow remained brilliant for some time, and was very bright on September 30. The haze stratum was visible, as a continuous sheet, at a height far above that of the highest cirrus, a slight

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* 'Honolulu Saturday Press,' September 22, 1883.

wavy ripple being noticeable in its structure, always perfectly transparent; it was invisible except under certain conditions. A conspicuous circle of 15° to 20° radius was observed during several days,—"a misty, rippled surface of haze, with faint crimson hue, which at the edges of the circle gave a purplish tint against the blue sky."

Mr. L. HARGRAVE, of Sydney, N.S.W., wrote as follows to the 'Sydney Herald' on September 25, 1883:—"With regard to that pink glow that has been so persistent at sundown lately, a casual glance will convince most persons that it is not the ordinary red sunset. Its bearing from S.W. to W., and even north of W., is a fatal objection to the Aurora Australis theory, so I hazard the opinion that volcanic dust is the true solution."

On December 29 Mr. L. HARGRAVE wrote as follows to the 'Herald' (published January 2, 1884):—"I have observed the sun to set in a cloudless sky, coloured orange-yellow; the daylight seems to decrease for 15 or 20 minutes after sunset, when I observe a whitish oval patch of light at an altitude of 20° or 30°; this rapidly changes in colour, becoming yellowish-purple, pink, brick-red, and crimson, the coloured patch of light at the same time elongates and settles rapidly down on the horizon, this phase ending about 45 minutes after sunset. A second purplish patch then appears at about 30° altitude, the horizon turning to a brown colour. This second patch is more widely diffused and its boundaries are more ill defined than the first one; it changes to yellowish-purple, yellowish-red, brick-red, and crimson, spreading in azimuth, and settles down on the horizon in about 100 minutes after sunset, when the last tinge of colour disappears.

The Rev. W. R. MANLEY* wrote as follows from Ongole, India:—"On September 10, 11, and 12, the sun had a greenish-blue tinge, and was somewhat dimmed by a haze in the afternoons. At 4 p.m. the colour was bluish. This gradually passed into a greenish colour, and this in turn became tinged with yellow as the sun approached the horizon. As the sun sank, bands of smoky haze drifted across its disc. After the sun was down, bright yellow, orange, and red appeared in the west, a very deep red remaining for more than an hour after sunset; whereas under ordinary conditions all traces of colour leave the sky in this latitude within half an hour after the sun disappears. At night the moon, just past the first quarter, was surrounded by a pale greenish halo about 30° in breadth. After sunset I observed a peculiar appearance in the haze which covered the sky. It was not of sufficient density to be at all visible, except where it reflected the direct rays of the sun. There it had a singular mottled appearance, with a smoky look along the borders of its denser portions, suggesting clouds of smoke or dust in the upper regions of the atmosphere. . . . On the evening of the 13th the sun appeared to be perfectly clear, but after it was below the horizon the western sky was seen to be covered with a smoky haze of a

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* 'Nature,' vol. xxviii. (1883), p. 576.

singular appearance, which became brilliantly illuminated with yellow, orange, and red, in the order I have mentioned, counting upward from the horizon. These sank one after another, leaving at last an arc of brilliant red along the west; the inner portion of the segment contained by the arc being composed of orange. This disappeared in turn, and the whole western sky became yellow again without any distinct outlines; and this gradually deepened into red, which remained for an hour or more after sunset. The latter phenomenon was not unlike an ordinary sunset, except in brightness and duration. . . ."

The following is an extract from the account sent us by Mr. H. Parker, of Hambantota, Ceylon, referring to the various phenomena seen in Ceylon in September, 1883:—"For several evenings previous to the first green appearance of the sun (September 9) we had magnificent sunsets, the sky in particular being of most peculiar and varying shades and colours, in which delicate, beautiful, blue-and-reddish-purple predominated, more like the aurora borealis, but brighter and deeper in tone than any I have seen in the atmosphere.

"*September* 24.—Just before sunset we observed the same green appearance in the sky and over the sun's disc as before, but not so vivid a colour. The greenness was very noticeable for some considerable distance around the sun, tinging even the surrounding clouds, which were high. The sun's disc was clearly-defined, greenish-yellow, but around it the green was much more distinct. . . . There was also a hazy appearance in the whole sky, especially noticeable just after sunset, when the general colour became peculiar and blue-leaden, except in the quarter where the sun had set, where the zodiacal light was whiter. Fully half an hour later the sky was still of this blue-leaden colour, and in the west of a dull orange glow, rather bright near the point of sunset. The stars afterwards were not perceptibly obscured. Immediately after sunset there were broad distinct palish streaks pointing west, beyond the boundary of the zodiacal light, apparently streaks in the haze.

"On September 25 and 26 the sunsets were similar, the sun in setting slightly green, then a dull yellow glow near the horizon, and a blue-leaden sky long after sunset."

Dr. C. Meldrum, F.R.S.,* says:—"The optical phenomena which have been observed, generally presented the same features throughout, and do so still. During the greater part of the day the sun is surrounded by a circular patch of whitish silvery light, on the outer borders of which there is a brownish fringe, the diameter of the whole varying from 12° to 24° between 8 a.m. and 4 p.m., according to the sun's altitude and the state of the atmosphere. As the sun approaches the horizon the silvery patch extends more and more above than below him, until at length it is entirely above him. It then becomes greyish watery looking; and beyond it, towards

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* 'Proc. Met. Soc. of Mauritius,' October 27, 1883.

N. and N.W. and S. and S.W., the sky has a brownish smoky appearance down to the horizon.

"At about 4 minutes after sunset the sky becomes slightly purplish at 30° to 45° above the point of the horizon where the sun has set. The purple soon becomes red; below the red are orange and yellow; and below them there is a bluish band, into which the greyish watery patch has been gradually converted. Along the horizon, to the extent of 30° on each side of the point of sunset, there is generally a low brownish-yellow band, which seems to be partly due to smoke from the sugar-mills. Between 23 and 26 minutes after sunset the grass, trees, &c., assume a yellowish-red colour. The red band, which is the most prominent, commences about 19 minutes after sunset at an estimated altitude of 40°, and lasts 21 minutes, its width and altitude decreasing until it vanishes on the horizon. At first it extends as an arc from W. by N. to S.W. When its upper edge has descended to 10° above the horizon, it becomes fiery red, and when nearer to the horizon, dark red.

"The blue, yellow, and orange disappear in succession before the red.

"At about 10 minutes before the disappearance of the red band, the sky above it, up to 40° or 45°, begins to assume a greyish-green colour, and after the red has disappeared this large new patch of colour, which is now inclining to yellow, is the only remarkable feature.

"The upper part of the new patch becomes red about 44 minutes after sunset, at about 35° above the horizon. This second red band lasts 32 minutes, or till 1 hr. 16 mins. after sunset. At first it forms an arc extending from W.N.W. to S.S.W. Below it there are narrow bands of orange and yellow, and occasionally below them a bluish band, all which disappear before the red. The latter is most intense when its upper edge has an altitude of about 20°; it then deepens into a dark red, and finally dies out on the horizon.

"In the morning the phases are reversed. The first red band, which commences on the horizon about 1 hr. 16 mins. before sunrise, corresponds to the second red band in the evening, and the second red band in the morning, which commences on the horizon about 39 minutes before sunrise, corresponds to the first red band in the evening."

Mr. TODD, C.M.G., reported as follows from the Observatory at Adelaide, South Australia, in October,* 1883:—

"On every clear evening during the month a peculiar phenomenon has been apparent in the western sky. Shortly after sunset a red glow will make its appearance at an altitude of about 50°, being very faint at first, but as the brightness of the sky near the horizon dies away with the receding sun the red glow will expand downwards, becoming at the same time more brilliant, until at last the whole western sky will be lit up with a beautiful light, varying from a delicate pink to a very

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* 'SYMONS'S Monthly Meteorological Magazine,' vol. xix. (1884), p. 78.

intense scarlet, and presenting a very brilliant spectacle. The upper part will then gradually fade away until the colour is noticeable only 7° or 8° above the horizon, at which time the light is at its brightest. Afterwards a secondary glow will sometimes make its appearance at an altitude of about 50°, and again gradually spread downwards until the sky is again lit up. In the secondary phenomenon the sky is generally more delicate. The whole thing will fade away at about 8 p.m. This phenomenon has been noticed all over the S.E. portion of this continent, from Port Augusta to Melbourne."

In a great part of northern Germany, on the evening of November 27 and early on the 28th, a peculiar light phenomenon was seen, of which a correspondent at Magdeburg wrote* :—"Already, at 5.30 a.m., a reddish glow of the twilight arc was seen in the S.S.E., which quickly augmented in breadth and height; the splendour of colours was not quite equal to that of the preceding evening, but towards 6.30 the whole sky, from N.E. to S., seemed to be bathed in shining purple. At 6.45 the carmine tint predominated, which appeared in a very distinctly marked flat arc. At 7 a.m. the more elevated arc was of so pale a yellow brightness that one might suppose that the sun had already risen. . . . The sun rose at 7.43. On the evening of November 27 the time of the visibility of the arc was 2 hrs. 13 mins.; on the morning of the 28th also 2 hrs. 13 mins."

Herr Dr. A. GERBER wrote* from Glückstadt as follows :—

"The phenomenon was most fully developed here, as elsewhere, from November 26 to December 1, but did not suddenly cease at the latter date, for there was an unusual colour in the sky for many days, more particularly before sunrise. The display of November 29 was the grandest and most manifold, and I give a description as exactly as possible of this one, as its overwhelming magnificence still presents itself to me as if it had been yesterday. When the sun had set about a quarter of an hour there was remarkably little red (or ordinary) after-glow, yet I had observed a remarkably yellow bow in the south, about 10° above the horizon. Soon—that is, after about 10 minutes more, when it was at least half-past four—this arc rose pretty quickly, extended itself all over the east and up to and beyond the zenith. The sailors declared, 'Sir, that is the Northern Lights!' and I thought I had never seen Northern Lights in greater splendour. After 5 minutes more the light had faded, though not vanished, in the east and south, and the finest purple-red rose up in the S.W.; one could imagine oneself in Fairyland. The S.W. sky was bathed in an immense sea of light red and orange, and till more than 1½ hours after sunset the colouring of the sky was much more intense than it is half-an-hour after a very fine sunset in ordinary conditions."

Mr. JOHN TEBBUTT, F.R.A.S., of Windsor Observatory, N.S.W., wrote as follows† on November 15, 1883 :—

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* 'Met. Zeitschrift,' vol. i., p. 185.

† 'Sydney Herald.'

"The appearance presented by our evening skies for some weeks past has been the subject of general remark.

"Last evening, November 14, the sky was almost cloudless after sunset, and the usual brick-red light again made its appearance along the west-south-west horizon. It was reflected apparently from an almost invisible and gauze-like cloud in the higher regions of the atmosphere. About 7 o'clock the red glow was at its maximum, when a solitary cloud, whose apparent surface did not exceed ten square degrees, presented itself above it at an altitude of 25°. This cloud, which was at first white, quickly changed to a beautiful green, its borders being of a deeper tint. Of all the cloud phenomena that I have witnessed, it was one of the most remarkable. It retained its green colour for the space of about 10 minutes, being all the time subject to much internal commotion. It soon afterwards resolved itself into several cloudlets and finally disappeared. Two or three other small clouds were visible at the same time, and about the same altitude above the northern horizon; but these were of a grey colour throughout. The eastern sky about the moon was of that deep blue which is frequently observed to surround her when rising during the winter oppositions. Shortly after the dispersion of the green cloud the ruddy glow gave place to the ordinary, pale gray of the twilight, but by half-past seven o'clock the western sky became diffused with red, but this time of a clearer and more aurora-like tint. It did not appear, as in the former case, to be reflected from hazy cloud, and it extended much higher in the sky. This repetition of the ruddy glow on the same evening is a phenomenon which I had witnessed on several occasions during the present month. I remember that many years ago (probably twenty-five) a somewhat similar patch of red light used to make its appearance regularly after sunset in the west-north-west. This phenomenon occurred previously to the commencement of my regular meteorological observations in 1863, and was, I think, contemporaneous with a very dry winter.

"That the present ruddy skies are not merely a local phenomenon is obvious from the fact that during the past three months they have been regularly observed over a considerable portion of the Indian Ocean."

Herr G. MEYER wrote,* at the end of December, as follows:—

"The twilight phenomena occurred here from the 26th of November, and lasted till 5.45 p.m. On the last days of November their course was such that at first a strong evening redness developed itself, which lasted till 4.30 (and similarly a morning redness). At this time the whole sky shone with a yellowish colour, and from 4.45 a purplish glow developed itself, which attained its maximum at 5, and sank down to the horizon till 5.30. On other days these periods were not so sharply distinguishable. On December 19 the phenomenon was absent. On December 5 the moon had a large circular corona. The sky is, in a striking degree, never pure, even with a

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* 'Met. Zeitschrift,' vol. i., p. 161.

high barometer and calm weather; in weather otherwise clear the sun is surrounded with a sheen."

The following are local notes taken in Surrey by the Hon. F. A. Rollo Russell (MS. Register):—

"The first sunset which showed any effects of a very striking or extraordinary character was on November 9, 1883; but, on referring to private notes taken daily during the summer and autumn, I find that as early as September 8 a 'fine red sunset with after-glow' is mentioned, and this is worth remarking, because I had never previously used the expression 'after-glow.'

"On September 9 a 'great succession of small cirrus-like masses' was noted, 'and fibres, clearly marked; very high small cirro-cumulus, vastly higher than the cirrus, also high. Beautiful rainbow colours in cirrus and cirro-cumulus near the sun. All coming from W. against surface wind.' The remarkable feature in this condition was the great elevation of the cirro-cumulus above the cirrus, and the colours were certainly quite uncommon.

"On September 26 there were 'light pink cirrus stripes' at sunset.

"On October 3 there was a 'red and yellow sunset.'

"On October 20 there was a 'fine reddish sunset, with bright isolated cloud and slight low cirrus.'

"On October 21 a 'fine reddish and orange sunset.'

"On October 22 'sunset in bath of cirrus; halo effect, red. Rest of sky clear.'

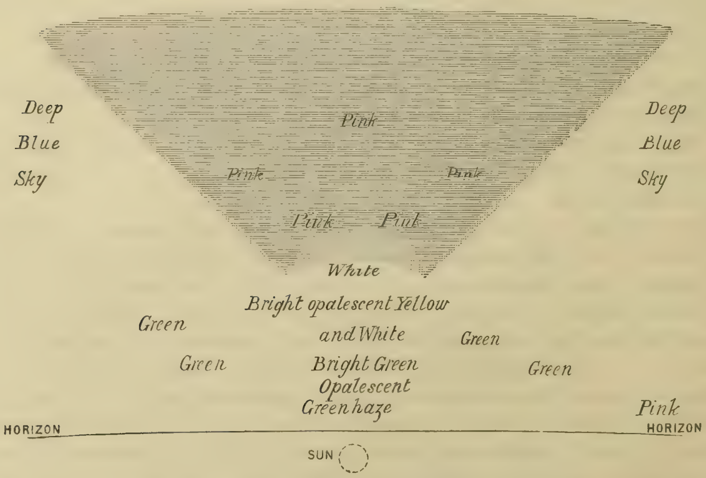
"On October 23 a 'clear sky, but white mistiness on horizon' at sunset.

"On October 27 'fine-weather sunset; some streaks of soft delicate cirrus in irregular patches, turning fine pink at sunset; glow from horizon.'

"On November 8 a 'fine sunset, with straight horizontal lines of cirrus (?) and very slight bank. Long after sunset, and till nearly dark, a pink glow from some very high filmy cirrus."

The following is transcribed from the notes taken on November 9:—"Series of ripple cirrus in web-like uncrossed striæ, transverse; well-defined morsels of high cirro-cumulus; some cirro-stratus. At 7.30 a.m. there was some high pink filmy cirrus, like last night. 11.20 a.m.—Blue sky, but some large patches of very high cirro-cumulus, one overhead; smallest fleeces; part consisting of re-curved waves or bars, small. . . . Heavy shower 1.50 to 2.5 p.m. Fine after this shower; sky cleared of cirrus and cirro-cumulus, and general appearance quiet. . . Sun set in very slight haze bank or cirrus; remarkable whitey-greenish opalescence above sun at sunset. About 15 minutes after sunset the sky in W.S.W., from near the horizon up to about 45°, was of a brilliant but delicate pink. Below this a very curious opalescent shining green and slightly greenish-white, the pink opalescence going off into bronze-yellow, and that to the green tint. The coloured portion of the sky spread out like a sheaf from the horizon, and apparently consisted of a very high thin filmy cirrus disposed in transverse bands, or ripples, close together, and very delicate in form, outline, and tint. At sunset some morsels of cirro-cumulus were lighted up with a light red fading to a deep red, but this soon passed off. What remained seemed not to belong to clouds, but to glow of itself, like some super-atmospheric film. The bright pink colour continued, and even increased in brightness, and at 5 o'clock cast a fine glow over the east hills and on objects exposed to it. The moon was shining brightly. The colour now began slowly to recede towards the horizon from the part most nearly overhead, and left a clearly visible filmy ripple of cirrus (apparently) of a soft grey. When, however, at 5.25, the greater part of the colour was gone, and it remained bright only near the horizon, it began to grow again, and in a short time (5.32) the whole extent of the film was again glowing bright pink, producing a very striking effect in contrast with the silvery moon, dark sky, and bright stars in the north and east. It was now almost dark, except for the moonlight and the cirrus glow. The pink light then slowly withdrew towards the horizon, remaining bright and deep-coloured there till 5.50. At 5.58 the last pink colour disappeared.' The sight was, altogether, a very extraordinary one, and unlike any in the writer's experience. It was remarkable, first, for the light filmy character of the cloud (if cloud it was); next, for the wavy form of the cloud; thirdly, for the bright green glow near the place where the sun set, and the strange yellow light above the green; fourthly, for the very long endurance of

FIG. 13.—*Diagram of Sunset Colours*



the whole phenomenon. It was supposed to be due to cirrus or a high kind of cloud, because (1) similar clouds stretched in long streaks southwards and over the S.E. horizon, and the glow remained long in these streaks; (2) when the light retired it remained visible as silvery-grey cloud ripples before the second after-glow re-kindled it; (3) because the colour became (but very gradually) darker as time went on, and the recessions towards the west followed the sun. There was no apparent movement of the cloud during the time of the display; the form remained the same throughout, and was distinguished by the clear demarcation of the film towards W. and E., the cessation of the cloud and the glow towards the zenith, and the long streaks stretching *apparently* horizontally near the horizon. The sunset light of the sun was peculiarly yellow. The ripples of the luminous film were transverse to the sun's rays.

"On November 10, at 6.20 a.m., there was 'a pink sunrise light in the extreme east,' the rest of the sky being cloudy. During the afternoon, about 3.30 p.m., and later, 'a very thin high cirrus ripple haze became visible in parts of the sky, especially S.W. About 4.32 this became more distinct as it began to glow with the light of the clear sunset (4.18), and became bright pink, lasting till 5.10. As the light faded off it, it entirely disappeared in the deep blue sky. The ripple was very small, close, and fine, and lay to the left, or south of the place of sunset, up to about 25° from the horizon.'

"On November 11 there was pink cirrus in the E. at 6.10 a.m.

"On November 17 the sunset was clear.

"On November 19 there was a 'clear sunset with white mist.'

"On November 23 there was 'sunset in cirro-stratus or cirrus bath.'

"On November 24, 'after sunset yellowish-green striæ in W.'

"On November 25, 'sunset in amorphous indistinguishable cirro-stratus or cirrus haze. Green light above sunset, and bright greenish-white growing from about 10 minutes after sunset. Above the greenish-white pale red or pink. Lasted about 45 minutes after sunset. The sky shone somewhat as on November 9, but much more feebly.'

"On November 26 similar phenomena occurred more strongly, and lasted nearly an hour. Also on November 27, lasting till 5.20.

"On November 28 the glow began about 25 minutes after sunset, and was succeeded by a faint brass-coloured secondary glow.

"On November 29 a similar glow was seen through breaks in the clouds, and the newspapers gave an account of an extraordinary redness in the sky from 5.30 to 7.30 a.m.

"On November 30, at 6.5 a.m., there was a fine deep red glow in the E. This spread quickly upwards, and had turned yellow by 6.40. At 6.24 the faint redness extended to the zenith. There was no cirrus visible, but some cirro-cumulus remained, tipped with dull red from 6.5 to 7.44, when the sun rose.

"On December 4, when the sky was again clear, the first redness appeared in the E. at 6.5, and at 6.10 'was quite bright, like the reflection of a fire.' It appeared continuous and without defined shape. By 6.30 the red had slowly changed to a saffron colour, and being seen less in perspective, seemed less concentrated. The reflecting matter, or a part of it, was now seen to consist of ill-defined streaks and patches of misty cloud of some sort, in which, after long watching, no motion could be detected. At 6.45 some of these streaks were illuminated nearly overhead southwards of a pale straw colour and bluish-white, and their outlines were distinct. Most of the streaks stretched about W.S.W. to E.N.E., and towards the N.E. the appearance was like a fretwork of the lightest wavy mist. From 6.30 to 6.50 the glow was of a sickly yellowish-green, with a pale pink towards the zenith, and a rather ghastly white glare below. At 6.53 a second glow, much brighter than the first, appeared in the E.S.E., of a deep red colour, quickly turning to orange. This glow was in a bank or arc much better defined along the top than the first. At 7.10 it had turned quite yellow, and had grown up to about 15°. At 7.16 the last star disappeared in the bright light which was now cast on all objects towards the W.; the clear sky, as the light touched the thin high mist, appearing progressively veiled. Just before the advent of the second glow the thin cloud streaks had nearly vanished, but as this new light grew and changed to bright yellow they became again illuminated. At 7.12 the upper part of arc No. 2 was yellow, with a greenish-white central part below. At 7.20 the part below the arc, and along the horizon south and north for some distance, was a peculiar steely bluish-yellow, and the upper (at an altitude of about 50°) pink. These effects slowly diminished, but the steel colour remained till sunrise. At 7.23 the sky overhead and towards the W. was faint pink, with large billowy streaks and patches like murky cirrus, without fibrous structure. This cloudy appearance was sufficient to hide the blue sky, when the cloudy matter was illuminated from below; but in full daylight only faint traces remained. At 7.50, and for some time after, this cloudiness was again made plainly visible by the rising sun, as by the first and second glow. Twelve minutes' careful watching failed to discover in them any uniform progressive motion, though their shape slightly changed. The sun rose at 7.55, of a red colour, but in about half an hour was pale steely-bluish white, and surrounded by a silver-white sky, with a slight bluish tinge. During the day the billowy high mist was faintly visible, but the sky was bright blue. As the sun was setting (3.53) this high haze became so white by reflection that the sky looked quite clouded with it. Nothing otherwise remarkable appeared till 4.12, when it was evident the phenomenon would recur; the central spot above the sun's place being bright steel or lead colour, and the parts round it a metallic pink, this has been the usual preliminary. The sky in the east was rosy. The rose colour quickly passed over towards the west, and about 4.20 the whole sky between the western horizon and the zenith was flushed with red. At this stage the forms of the haze-billows and streaks seemed to be lost in the uniform rosy glow; this glow slowly sank down to the horizon as usual. At 4.25, or thereabouts, the crescent moon appeared blue in this pink haze, but in a few minutes was left behind and appeared much as usual. The small stormy scud from N. was lighted up pink against a deep blue and green sky towards the E. and overhead, and in the S.W., near the moon. As the glow sank westwards the sky seemed perfectly clear, without a trace of the billowy haze. At 4.35 the bank of light was very bright. About 4.45 it was lost to view behind low clouds; as it approached the horizon the sky again became mottled with the reflecting haze, which assumed a straw-coloured tint. This pale light again sank westward and vanished soon after 5 ; the moon and stars gave no indication of a haze canopy. It seemed to be without motion, and was disposed in very large billows, their length lying about S.W. to N.E. on both sides of the glow, but crossed in some parts by a thick streak nearly at right angles.

"On December 5, 'exactly at 6.5 a.m. the first faint red blush grew up quickly from the E.S.E., and in 7 or 8 minutes had increased largely in brightness and extent. The night was very fine and clear and the soft crimson glow hanging above the horizon in the darkness produced an interesting effect. It grew rapidly up towards the zenith, and at 6.18 formed an arc, of which the highest point was about 40° from the horizon. After this it quickly changed to orange and yellow, and the colours went off. The arc was more southerly than yesterday, and the peculiar light reached from S.S.W. to N.N.E. At 6.55 the second glow began ; and rising up quickly, produced a fine red arc, less bright than that of yesterday morning. At 7.6 the arc was olive-green below, yellow in the central, and pink in the outer parts, and hardly any cloud structure could be discerned. What there was, however, seemed to resemble the film of yesterday. The upper edge of the glow, as it advanced, was pretty well marked, and at 7.12 it crossed the zenith and passed north-westwards, covering a bright star in that direction with a thin pink veil. This star continued visible till 7.21. The sky after this time was pale yellow, and little of an uncommon character remained, except the greenish light in the east. Sunrise, 7.51, red sun, turning silvery-white later. Sunset, 3.50, in hazy striæ. At 4.15 yellow glow appearance began and went through usual changes. The light was pink overhead about 4.25, and the margin (ulterior) passed over about 4.26. The glow grew more and more red, as usual, in sinking down, exhibited spokes of rays, and disappeared at 4.45. The second illumination was brightest about 5.5 and disappeared a few minutes later. At 4.30 the moon looked blue, like yesterday, in a pink haze. The horizon was misty. The crescent moon shone all the evening with a greenish light.

"On December 7 it was remarked that the reflecting matter in the west after sunset first shone with the rays of the setting sun between 20 and 29 minutes later than the cirrus above which it floated.

"On December 11 the sky was perfectly clear and cloudless about an hour before sunrise, except a little detached scud. At 7.21 a.m., as the light of the primary glow spread to the zenith, the sky was seen to be striped with very high filmy streaks in the S.E. At 7.32 this appearance extended over the N.W. Obtaining a good view of the streaks in the S.E., I tried to discover their motion. After about 10 minutes' watching, one of them showed a translation from W.N.W. of about half an apparent solar diameter in that time. At 7.35 and 7.40, the whole sky being covered with these long thin stripes, like the "billows" of a few days before, but not so wide, it was found that they extended on all sides from south to north or S. by W. to N. by E. One point seemed worth special notice. Those in the extreme west, that is, 10° or so above the horizon, as well as in the east, did not appear, like ordinary cirrus lines, to radiate from a point on the horizon. On the contrary, they were all seen to be lying in the same direction, and the stripe furthest to the west gave nearly as good an idea of its true direction as a stripe overhead. The eye made the necessary allowance for such appearance of convergence as there was; and they were at once seen to be parallel. At 1 p.m. the streaks of sky-haze reappeared, stretching from S.S.W. to N.N.E., and were watched without any motion showing itself, though when looked at after the lapse of 15 or 20 minutes they seemed to have moved a little transversely eastwards. Their very indefinite appearance in the daytime made exact observation difficult, and at times the strong sunshine seemed to obliterate them altogether. . . . At 2 p.m. a stripe of upper haze in the S.S.E. was watched for 10 minutes, and no motion discovered, either transverse or longitudinal. The stripes were observed through dark glasses, which increased their visibility. At 4.15 green spot about 10° above horizon. Pink up to and beyond zenith, and on both sides. Small cirri from sunset till 4.10 pink, then light dusky green. Whole sky at 4.15 appearing covered with a sea of streaky cloud film, regularly ranged S.S.W. to N.N.E.; no appearance of a radiant point. At 4.20 spot of green being closed in by bright pink all over western sky; 4.23, pink seemed to pass zenith. . . . At 4.30 pink edge about 22° from horizon. Green sunk beyond horizon. At 4.36 pink, about 15°. Sky blue. At 4.41 edge of red glow about 10° above horizon. Sky beginning to be lighted up from below, and to appear cloudy again. At 4.48, blood-red to about 7°. Cirri in E. peculiar dull pink. Moon very slightly bluish. 4.55 last red disappeared. Second glow just past zenith. Usual phenomena of second glow, like first over again, but less bright. At 5.18 red arc very fine. Almost gone 5.30. Just visible 5.33.

"On December 15 there was 'a yellow glow in the S.E. at 6.18 a.m., which grew up as usual. Very fine clear sky with bright greenish moon (full) in the W. Not the slightest halo or corona by the moon during night or morning. Greenish light above sun at sunrise, &c. Sky now (7.40) seems to be streaked with haze billows (length S.S.W. to N.N.E.) as on previous days. The western sky showed this marking very clearly at this time, but it quickly became less and less visible towards sunrise. It remained visible, however, over the S.E. for a long time, and after sunrise for at least three quarters of an hour. The western sky, at 7.40, looked as if covered with a cloud of a streaky cirrus character, only more regularly disposed in bands, like a great ocean covered with regular billows. There were, however, some spaces clear. At 8 all this (in the west) had melted into blue again. From 8 to 8.30 a.m. I watched the distinct streaks in the S.S.E., the branches of an oak giving the means of discovering motion in any direction. Half an hour's watching failed altogether in detecting the slightest general movement, though there was a slight change in the breadth of one of the streaks. After the sun had risen about a quarter of an hour, the stripes in the W.N.W. again grew quite distinct, but did not obliterate the blue sky as before."

In further daily notes on the sky-phenomena, the following points may be mentioned:—

"On December 21, the clouds remained red 1 hr. 15 mins. after sunset. At 4.22 p.m. the cloudy matter or high haze very unexpectedly appeared in the west and nearly overhead, the sky not having seemed transparent enough to show it. It was in the form of a hazy, white ripple, the waves close together and regularly disposed, but not all in the same direction in different parts of the sky. Some were stretched from S.W. to N.E., others from W. to E. and S.S.W. to N.N.E.

"On December 23, the evening glow was exceedingly beautiful, exhibiting radiant spokes. About 4.30 the clear sky between the zenith and the horizon became as if veiled with a very delicate, thin, structureless mist, which completely hid the blue. This was at first greenish-yellow below, and then turned to a very fine amber below and pink above. At about 4.35 the glow may have been at its highest point, about 35° or 40° above the horizon. It sank below the horizon at about 4.52. At about 5.5 the secondary glow extended to the zenith, and remained an exquisite faint pink (near the horizon) till 5.25. On both sides the sky near the horizon was clear blue or green.

"On the last days of December, which were foggy and cloudy, a pinkish light affected the mist as early as 7.30 a.m., and sometimes after sunset.

"The glow continued during January. On January 24, the hazy stripes were very plain over the western sky, and during the whole morning, in the neighbourhood of the sun, making a sort of sheen close to the sun; their motion was imperceptible in ten minutes' watching. After sunset the ulterior margin of the glow passed overhead about 4.57; set at 5.20. Second glow about 25° high at 5.40.

"There was a marked diminution of all the effects at the end of January. The sun was surrounded during the day by a brownish-pink, faint, and ill-defined circle, and between this and the sun there was a bluish-white sheen or glare.

"In February, the duration and intensity of the glow decreased further, and it was of a yellow colour, or faint green and pink.

"On March 6, there was a slight repetition of the sky-illumination, lasting only 30 minutes, but during March the glare completely vanished, and no illumination whatever appeared in a clear sky after sunset. During the remainder of the year the sunsets were uncommonly free from colour, even promising skies turning grey soon after sunset, and no redness of an ordinary character remaining along the horizon after sunset, except on a few evenings and in a few localities."

Local Notes taken at San Remo, Italy, and Cannes, France, from January 5 to January 14, 1884, by the same observer :—

"On January 5 and 6, the glow was visible but not striking at San Remo. The hazy streaks lay from S.W. to N.E.

"On January 7, there was a fine yellow after-glow, lasting about an hour.

"On January 8, there was a fine clear sunset with the sky-haze very distinct in billows or streaks exactly as in England, but very faint, S.W. to N.E. Duration about an hour, chiefly yellow.

"On January 9, the sunrise was extremely clear and fine. The time from strong twilight to sunrise was 61 minutes, from the primary glow at about 5° to sunrise 41 minutes. Before sunset the streaks again appeared in an intensely clear blue sky, about S.W. by W. to N.E. by E. About 10 minutes after sunset the sky was beautifully rosy in the east and slightly rosy in the north, and towards the zenith in the west. In the west bright peacock green. At 23 minutes past sunset the upper margin of the pink passed the zenith. The west now turned bright yellow. At 35 minutes past sunset the red was lost in the yellow western sky. At 37 minutes the edge was about 10° above the horizon. A beautiful secondary glow appeared at 55 minutes, the evening star looking blue through the pink haze.

"On January 10, the air, sky, and horizon were perfectly clear. At 22 minutes before sunrise a beautiful purplish-pink film extended between about 40° above the eastern horizon and the zenith. Below this in the east was a green sky, and along the horizon an orange band, which no doubt was the ordinary effulgence of sunrise. All the sky colour soon went except the strange green in the east. The sun rose like a gush of white-hot iron, instantaneously brilliant, from the sea line. Corsica, over 100 miles distant, was very clearly defined. The streaks in the sky appeared as usual before sunrise, and were lying S.W. by W. to N.E. by E., obliquely to the rays of the rising sun.

"At sunset all the atmospheric conditions were absolutely perfect for separating the sky-glow from all accidental interference. The sky was transparent and cloudless. After sunset came the bluish-white arc. At about 22 minutes after sunset the condition was as follows :—Orange ordinary glow in S.W., near horizon ; above this a greenish-bluish white arc, then a beautiful yellow band ; then up to the zenith a very beautiful lilac tint. All these colours were of extreme softness, and though not so striking as in some of the sunsets in December, in point of beauty they were quite unsurpassable, and of superb magnificence in their further progress. The pink, purple, or lilac, now retired in the most steady and regular manner towards the horizon, and were visible to the end ; 35 minutes after sunset the arc was formed of the inner part, which from steel-blue had gone through olive-green to yellow, the middle, yellow, and the outer, purple. Through the fringe of this, Venus shone beautifully. The horizon (about a quarter of the circle) was deep yellow. The purple part being the smallest was flooded, except at the edge, by the orange light, which shone in a grand arc for a long time with great splendour, casting shadows. In about 54 minutes the primary glow was gone, having sunk in a deep red band. The eastern sky during the first part of the display was a glorious deep blue, then very dark purple-blue, and lastly only illumined by the silver moon. The secondary glow was very visible, as the thinnest pink or lilac film, 1 hour after sunset. It disappeared on the horizon about 1 hr. 20 mins. after sunset. The sky streaks were less distinct than usual.

"On January 11, the sunrise was not so fine, but the sunset (at Cannes) gave magnificent effects. About 22 minutes after sunset the ulterior margin (well-marked) of the primary passed overhead, leaving the east deep azure. As the green gave way to the yellow, the yellow to pink and violet, and the final deep red band shone out by itself from above the Esterel Hills, the most enchanting effects succeeded each other in slow and regular order. Last red, 50 minutes; secondary glow 30° above the west horizon at 65 minutes past sunset, but had been very apparent up to and beyond the zenith while the primary was still bright, its first effect being a curious discoloration of the eastern sky. At 70 minutes, very fine, dull red, in west; just disappearing behind hills 82 minutes after sunset. The glows were seen on the following days, and in travelling through France on the 14th, 15th, and 16th."

Prof. O. N. Stoddard,* of Wooster, Ohio, writes as follows respecting the sunset phenomena at that place:—

"The main features of the exhibition here have been the crimson glow—the first and after-glow with other accompanying colours, closely corresponding with those in England and the continent of Europe. I have on record seven cases, which were nearly all that the weather would permit one to see. These occurred on November 27, December 9, 10, 25, 28, and January 13 and 17. The first and second glows have extended in two or three instances, though faintly, to the zenith, and the first has occasionally been reflected on the eastern sky. On December 28, the most brilliant exhibition in the series, an arc was formed in the east, the colours red and yellowish-green, very soft, and much blended. The crimson glow on the sky flooded the western sides of buildings with an unearthly light, and cast faint shadows across the snow. The appearance of the after-glow, when the sun had reached a certain angle, favours the view that it is a reflection of the first. If this be true, it is not necessary to admit so great an elevation of the reflecting matter above the earth. . . The glow has been seen without the slightest trace of cirrus clouds behind it. Three times faint ribbon-like stripes of cirri appeared in the first glow, but in the second the gorgeous crimson has generally been projected against the clear blue sky."

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* 'Nature,' vol. xxix. (1884), p. 355.

Prof. E. Divers, of Japan, says,[*] in a letter dated December 12, 1883:—"On some days there is round the sun, even while it is still high, a considerable area of silvery glare, 40° to 50° in diameter, and bordered by a lurid reddish-brown or purplish-brown halo. A similar lurid turbidity lies on the horizon, and as the sun descends the halo blends with this below, while above the sun it attenuates and disappears, the silvery glare remaining undiminished. When the sun sets there is still a nearly circular area of this intense glare, with a diameter of about 12°. On other days there is, before sunset only, a thin silvery light round the sun, diffusing away from it, and only about and after the setting is the more defined area of strong light strikingly visible, and on these days the horizon also shows little of the dull redness mentioned above. Besides the above-mentioned peculiarities the sun preserves its whiteness much more than usual, so as to be only golden-orange when setting. Now follow the more remarkable phenomena. The white glare, or patch of silvery light, gradually sets, spreading out along the horizon as it does so, and passing through the sunset colours until little more than a red line one or two degrees deep remains. This happens at about 20 minutes after sunset. At this moment, on the grey curtain of twilight appears a white luminosity, which rapidly intensifies over the sunset and shades away over almost half the visible hemisphere. The brightness over the sunset becomes vividly brilliant, and at the same time delicately coloured. Over a somewhat depressed circular area, about 12° high and 15° broad, it assumes a pale green tint. Above this comes an equally dazzling pale yellow-orange, and again above this a soft rose colour melts away to the zenith. The revival of the light, or return from commencing twilight, is peculiarly striking. Buildings become brilliantly illuminated, and strong shadows are cast. All this out-glow occurs in no more than 5 minutes, and then continues for about a quarter of an hour; but the brilliancy gradually contracts in area and sets with a magnificent display of sunset colours, reaching about 120° round the horizon, until, by 50 minutes after sunset, this light also has gone down to a red line of about 2° elevation. I should not have omitted to say that the green light passes to yellow.

"By this time night has fairly well come in the eastern half of the heavens, but already another but more delicate silvery whitening begins to show itself on the western curtain; and this also diffuses very rapidly up to the zenith and round to north and south. It also then goes through a process of contracting, intensifying to considerable brightness, and gradually passing through the sunset colours. Night is now full—with or without moonlight, according to date—and from the west, or rather from a point well to the north of it, spreads a delicate but brilliant light, having an almost perfect resemblance to the burning of a vast distant city. The last crimson light of this reflection does not disappear till an hour and a half after sunset."

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[*] 'Nature,' vol. xxix. (1884), p. 283.

Herr J. BAADER remarks[*] as follows, respecting a morning twilight at Marburg, in Steiermark :—" When I woke on December 1 towards 6 o'clock, I observed at once, through my window towards the west, an intense red ; mountain and valley were covered with a marvellous glow. The vineyards towards north and east, the Matzelgebirge, south and north-west, the snow-covered hills of Bacheon and Posruck, all was, including the whole sky, a sea of fire, the fog in the valleys like molten metal. About 6.45, on going out I saw, to my great astonishment, in the E.N.E. an arc spanning the sky, which was yellowish and in parts pure blue, up to about 20°. The boundary of the coloured space was sharply marked off from the blue firmament, and moved with great speed towards W.S.W., although there was hardly a light current of air. In a short time nearly the whole sky up to the zenith was free from the phenomenon—only in the far west a sharply defined arc appeared for a short time."

M. DUFOUR, in his pamphlet,[†] states the following facts regarding the twilight glows as seen at Morges, in Switzerland :—" They were first noticed in Switzerland on November 26 ; they diminished considerably at the beginning of December, increased greatly at the end of December, and were remarkable during the whole of January. They diminished during February, but did not altogether vanish ; till the end of 1884, when the weather was favourable, the sky was illuminated in the morning and evening as by an aurora borealis.

" On January 10, 1884, the redness began to appear at 6 a.m. ; at 6.30 the glow was in all its splendour ; at 6.45 it began to diminish ; at 7.5 there was a green zone above the mountains, red higher up ; at 7.15 the zone near the horizon was livid green, the red above it ; at 7.20 there was no appreciable redness.

" In the evening, at 5 p.m., the sky was yellow ; at 5.6 the red was conspicuous ; at 5.40 shadows were cast ; at 6.15 the redness disappeared.

" On January 11, at 5 p.m., the sky was yellow ; at 5.23 all the horizon was coloured red, even in the east ; at 5.25 there was a carmine zone in the west ; at 5.36 the red became very intense in the west, in a sector of which the sun seemed to occupy the centre ; at 5.45 the Alps lost their red colour, but there was intense glow in the west ; at 6.16 the last glow disappeared."

Capt. DE BRITO CAPELLO sent a report, published in the ' Standard ' of December 26, 1883, as follows :—

" Captain Capello, of the Lisbon Observatory, has sent us a succinct account of the late crepuscular phenomena of the rising and setting of the sun. In the first place, he remarks that they have been seen in feebler degree from October the 15th

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[*] ' Met. Zeitschrift,' vol. i. (1884), p. 162.

[†] ' Bibliothêque Universelle, Geneva, Archives des Sciences Physique et Naturelles,' Tome XIII.—February 15, 1885.

to the 23rd or 24th of that month, showing themselves in a region or segment of parabolic form in the west-south-west, the vertex inclining towards the north-west. This region was red-orange coloured close to the horizon; following this was a rose tint, more or less faint, and again an elongated region of very delicate pearl-white. The white region appeared to be formed of very fine cirrus and cirro-stratus, like skeins of white silk; the cirrus was not noticed before the setting of the sun, neither had the solar halo been seen which is always produced with the cirrus under normal conditions. According as this region moved down towards the horizon, the white light lost much in intensity, and disappeared, leaving, as in ordinary circumstances, a red-orange band close to the horizon. The red coloration elevated itself sometimes to the height of 30° to the west-south-west, and was seen an hour after sunset. The 18th October seems to have been the maximum of these phenomena.

"In the last days of November, and in the early days of December, these phenomena were observed in much greater intensity on some days, both at the rising and at the setting of the sun. Over and around the region of very vivid pearl-white, the colours of the twilight, very bright and exaggerated, the crepuscular and anti-crepuscular arcs, which, under normal conditions, are arcs of a circle, have shown themselves in parabolic form. The redness of the sky (red and red-violet) showed itself sometimes for two hours after sunset, and spread itself in very grand force to 60° and 70° of height. The duration of the coloration of the sky is most considerable at elevated points. Thus, at the meteorological station of Serra da Estrella, 1441 mètres in altitude, they have observed the redness of the sky up to nine o'clock at night. It should be remarked, also, that during all these days the sun was encircled by a region of whitish light, fringed with pale orange-rose colour. This region never appeared circular; one could not well define the figure it presented, as it had irregular borders, something like the corona of the sun in total eclipses. In the first days of December (1st and 3rd) these crepuscular phenomena showed themselves with greater intensity, and on the 3rd and 4th there was, at 4.45 p.m. Lisbon mean time, some minutes after the actual setting, on the side opposite to the sun (east-north-east), a segment which elevated itself from the horizon in parabolic form inclined towards the north. On the side of the west-south-west, where the sun went down, there was seen another much larger segment, affecting also the parabolic form, with the red, orange, and pearl-white colours, at first feeble, but augmenting rapidly in intensity. After a little while, towards 4.55, the pearl-white region showed itself silvery, and with the greatest splendour, the other colours preserving nearly the same relative positions, only between the white and the orange a band of very clear green showed itself. Then, at 4.58, there began to appear rose and clear violet colour encircling the white; and at 5 p.m. the rose elevated itself to the height of 50°. All the eastern side of the town was illuminated in a peculiar manner, and this illumination lasted for about 12 minutes. This rose tint, more or less violet, went up to the north, during which, in the south, one saw a broad band of orange-yellow. On the east side, the pale yellow at 4.55 p.m. was augmented in intensity, and showed itself very high (maximum elevation); the other colours presented themselves nearly in the same relative positions. After 5 p.m. all these colours of the east-north-east decreased rapidly in extent as well as in intensity, and in a little time (5.5 p.m.) there remained only a violet arc from north-east to south-east. Towards 5.3 p.m. the pearl-white region (west-south-west) sank little by little in the direction where the sun had set, losing its brilliancy, whilst above, a new region of yellowish-pink rose to 75°, extending from north to south. The sky at the zenith was then of a deep azure, almost black, and the moon showed itself of a green colour. A little later, 5.8 p.m., the exterior rose region presented itself streaked by different blue rays, which diverged from the point where the sun was below the horizon. The phenomenon was very like aurora borealis. Little by little the colours changed; the white region became very narrow, and, sinking towards the horizon, it assumed, at 5.15 p.m., a red-orange, bordered with gold. Soon after, the phenomenon ceased. At 5.18 to 5.20 p.m. the red coloration, more or less violet, extended itself rapidly all over the horizon from north to south, reaching, on the west, to 60° of elevation; and this red coloration maintained itself up to 6.30 p.m., that is, for an hour and forty minutes after the setting of the sun. Since the 3rd instant these phenomena have lost much in intensity, but all the characteristic points have been preserved—for example, the parabolic form of the crepuscular and anti-crepuscular arcs, and the white and coloured spaces. On the 12th, the redness of the sky was observed up to 6.20 p.m. During the whole period the magnetic curves have presented nothing extraordinary, apart from some little perturbations very common during the maximum of solar spots."

Professor von HELMHOLTZ* wrote from Berlin on December 1:—"The phenomenon called cloud-glow in your last numbers, was seen also at Berlin on the three evenings of November 28, 29, and 30. As far as I could observe the sky, the details were almost the same as your correspondents describe them: a greenish sunset at 3.50; an unusually bright red sky with flashes of light starting from south-west. An interesting physiological phenomenon, which we call '*Contrastfarben*,' was there beautifully illustrated by some clouds, no longer reached by direct sunlight; they looked intensely green on the red sky. At 4.30 the streets were lighted by a peculiarly pale glare, as if seen through a yellow glass. Then darkness followed and the stars became visible. But half an hour afterwards, at 5 o'clock, the western sky was again coloured by a pink or crimson glow. Persons who were not quite sure about its direction mistook it for an aurora; others spoke of a great fire in the neighbourhood. . . . At 6 o'clock all was over."

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* 'Nature,' vol. xxix. (1883), p. 130.

Mr. GERARD HOPKINS, of Stonyhurst College,* notes the following difference between ordinary sunsets and the displays of 1883 :—

"(1). They differ in their time and in the place of the sky where they appear.

"(2). They differ in their periodic action or behaviour.

"(3). They differ in the nature of the glow, which is both intense and lustreless.

"(4). They differ in the regularity of their colouring. Four colours in particular have been noticeable, orange lowest and nearest the sundown; above this and broader, green; above this, and broader still, a variable red, ending in being crimson; above this, a faint lilac. The lilac disappears, the green deepens, spreads, and encroaches on the orange, and the red deepens, spreads, and encroaches on the green, till at last one red, varying downwards from crimson to scarlet or orange, fills the west and south.

"(5). They differ in the colours themselves, which are impure and not of the spectrum.

"(6). They differ in the texture of the coloured surfaces, which are neither distinct clouds of recognised make, nor yet translucent media."

The above is merely an abstract of Mr. HOPKINS's letter, to which he subjoins a very lucid description of the sunset of December 16, 1883.

Herr Dr. E. von REBEUR-PASCHWITZ wrote,† on December the 19th, from Berlin :—"Yesterday, December 18, the twilight phenomenon, though much less grand, was very well seen. Soon after sunset, the western sky, which seemed to be covered with a very fine vapour stratum, but otherwise was cloudless, assumed a greenish-white colour. At about 4.15, at some altitude above the horizon, the first reddish sheen was observed; and it soon expanded over a larger oval space, and increased in intensity. This space filled with red light did not reach to the horizon, but was separated from it by a narrow streak of white of intense brightness. At last the whole horizon in the west shone with a beautiful orange colour. Yesterday, as on the 17th, a fine striation of the bright part of the sky was noticed. Broad streaks, inclined to the horizon, and nearly parallel, covered the western sky. The inclination of the streaks was variable; on the 19th they were nearly parallel to the horizon. This striation of the sky has been seen on three successive evenings, and also on the first days of December. Through an opera-glass the streaks looked like fine clouds, but could hardly be described as cirrus. At 4.53 the red glow was all but gone; at 5.2 there was another weaker redness, more towards the north than

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[*] 'Nature,' vol. xxix. (1884), p. 222.

[†] 'Met. Zeitschrift,' vol. i. (1884), p. 160.

before; at 5.5 a sudden renewal of the red glow; at 5.20 there was a diminution; and at 5.30 the glow had disappeared."

Mr. E. L. Layard* wrote as follows, on January 6, 1884, from Noumea, New Caledonia:—"As soon as the sun's disc has disappeared, a glow comes up from the west like that of white-hot steel, reddening somewhat as it mounts to the zenith, but changing the while to blue. From the zenith it passes into the most exquisite green, deepening as it loses itself in the east. As the sun sinks lower and lower, the red tints overpower the white-hot steel tints, and the blue of the zenith those of the green. At 7 p.m., or a little after, nearly the entire western half of the horizon has changed to a fiery crimson: as time goes on, the northern and southern areas lose their glory, and the greys of night contract, from the northern end first, most rapidly; the east is of the normal grey. The south now closes in, and presently, about 8 p.m., there is only a glare in the sky, just over the sun's path, as of a distant conflagration, till the fire in the west dies out. I have been attempting to describe one of our cloudless evenings, of which we have had only too many, having just come through a fearful drought that has lasted all this while; but who shall paint the glory of the heavens when flecked with clouds?—burnished gold, copper, brass, silver, such as Turner in his wildest dreams never saw, and of such fantastic forms!"

M. de Montessus, writing, "Sur les lueurs crépusculaires observées à San Salvador (Amérique centrale)," † under date February 9, 1884, says:—

"The remarkable sunsets have been seen here since the last days of November, 1883. About half an hour after sunset, and an hour before sunrise, the horizon is gradually illuminated with a magnificent coppery-red tint, very constant in colour, very intense, and lasting on the average 20 to 25 minutes. The phenomenon is not produced except in a cloudless sky. If there are a few strati on the horizon in the evening it is not produced; in the morning it may occur with a few strati, and especially with high cirri. The illumination extends, horizontally, at least 70° to the right and left of a plane passing vertically through the sun and reaches up nearly to the zenith; consequently, nearly half the hemisphere is filled with the splendid red glow. The moon, when circumstances allowed of it—that is, when her altitude did not exceed 15°, was coloured a magnificent emerald-green, and it was extremely beautiful to see it at the epoch of grey light (*lumière cendrée*), when its disc was of a pale green, with its crescent horn deep green in the midst of an immense crimson curtain. Venus only was able to penetrate the curtain, and was also green. Stars of the first magnitude could not be seen; and those which at a sufficiently great altitude, such as the small comet, were clearly distinguishable, were also green. The phenomenon rapidly acquired its maximum intensity, which it retained 3 or

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* 'Nature,' vol. xxix. (1884), p. 461.

† 'Comptes Rendus', xcviii. (1884), pp. 761, 762.

4 minutes only, and then as rapidly disappeared, after lasting altogether about 25 minutes. I did not at first note down the dates of the first appearances. There were two or three before November 30. Subsequently they were—November 30, December 1, 2; January 3, 4, 7, 17, 18, 21, 22, 23, 25, 26, 27, 28, 29, 30, 31; February 4, 6, 7. Yesterday the overcast sky allowed us to see it only at intervals for a few minutes. At Panama some of the old men report having seen similar glows before, but they could not recollect the precise year. The magnetic needle was quiet. There was nothing unusual recorded by the meteorological instruments. The centre of the glow seemed to be in the vertical plane of the sun. The zodiacal light was absolutely annihilated."

Mr. John BALLOT, of Roefontein Wakkerstroom, Transvaal, S. Africa, in a letter dated March 10, 1884,* says:—"The exact date on which the glow made its first appearance in this country, I am not in a position to give. It is, however, certain that it was observed as early as September 5, 1883. From about September 7, it had already become a very noted peculiarity after sunset, even to the most unobservant. The colour of the light was at first of a sickly greenish-yellow, but deepened into a copperish-red as the evening advanced; the light was strong enough to cast a deep shadow against a wall or anything else, if an object was held close to it. . . . The greenish tint of this glow seemed to me to prove that it was caused by light reflected and refracted by an atmosphere heavily charged with water vapour."

Therefore Mr. BALLOT predicted heavy rains and the disappearance of the glows. The rains came, but the glows, nevertheless, continued to March 10, the date of writing.

"The glow remained visible almost every evening whenever there was sufficient clear sky to reveal it. . . . One evening it would attain to a greater altitude than another, or be more brilliant. As time went on, the general colour of the light seemed to deepen to a darker copperish-red or muddy-orange, with a shade of rosiness diffused in its remoter parts. . . . The general tint is certainly much deeper than it was at first. The conditions most favourable to a grand display and cloud effect are a clear sky towards the time of sunset, with a few detached clouds floating about, and a slightly cloud-streaked horizon. When such has been the case I have frequently observed innumerable rays of the beautiful glow darting out from behind the cloudy horizon to great altitudes, and in every direction, the intervals between the rays being comparatively dark. . . . That the reflecting medium producing the glow is situated at greater altitudes than the general cloud layer is proved by the fact that these cloud masses appear quite black when projected against the rosy background. The thinner edges of such clouds frequently acquire a dark olive-green colour; while at other times I have seen them slightly rose-coloured by the reflection

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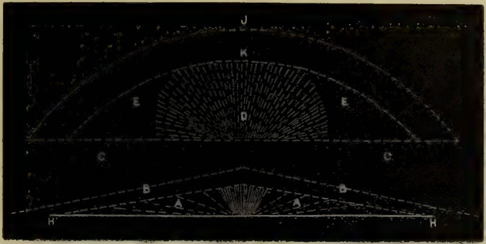
* 'English Mechanic,' May 2, 1884, p. 185.

of the glow, the cloud itself remaining a dark mass. . . A few concluding remarks will be devoted to the order in which the glow is generally formed. A rough diagram is annexed, simply to enable the reader better to understand the description.

FIG. 14.



"H H, *the horizon;* A A, *fading portion of ordinary twilight, with the point of sunset heavily shaded;* B B, *the brownish belt of glow due to denser lower strata;* C C, *vacant space between the two glows, above which the second glow begins to form;* D, *the bluish-white glare;* E E, *the copperish-red glow;* K, *where the purplish tint is brightest, fading into violet at* J.

"Soon after sunset, the usual twilight appears, which remains visible for a short while; as it gradually contracts and fades, everything seems to be settling down for the approaching darkness. The rosy glow over the point of sunset rapidly contracts, only a thin rim of red remains visible on each side, with a small arc of red marking the point of sunset. The observer will now begin to notice a peculiar bluish-white glare forming a few degrees above the arc of red, and extending some distance upwards. The white glare increases a little, when again a slight reddish tint makes an appearance round about the white. When once commenced, the red light spreads rapidly upwards and in a horizontal direction, but does not seem to make much progress towards the horizon. The fading rim of the first twilight forms itself into a long, narrow, brownish belt, stretching along the horizon, caused, no doubt, by the denser layers of haze and vapour lower down. Immediately above this belt, and just below the bluish-white glare, there remains an apparent blank; this blank is but slowly filled up by the new glow. It seems as if the reflecting media in that belt are below the line of reflection as yet. As the glow spreads outwards above the white glare, it seems to acquire a strong tinge of purple, which gradually fades into a violet near the borders of the spreading luminosity. The arc of bluish-white gradually gives place to a very strong copperish glare. But as the evening advances the light assumes a more uniform colour. The purple and violet entirely disappear, and the entire luminosity contracts towards the point of sunset, where it finally disappears at from one to one-and-a-half hours after sunset. . . . The glow generally has a much greater extension round the southern horizon than round the north-western. It frequently extends more than 90° round the southern, whereas it seldom exceeds 60° round the northern. Taking everything into consideration, there seems to me decided proof, from these observations, that aqueous vapour plays an important part in producing the after-glow."

Again, he says[*] that during March and April peculiarities were strongly developed which had not been noticed before:—"All throughout March I frequently observed it in broad daylight, especially one or two hours before sunset. But as the sky was generally covered with broken cloud I thought it peculiarly favourable to reveal the illuminated dust haze beyond, the sun himself being covered from view at times. April, however, brought a clearer sky, yet the glow forms an easily-detected daylight phenomenon. About 3 minutes after sunrise it is plainly seen on each side and along the horizon, even above the sun. The sides and lower portion of glow are of a brownish-grey, while above, or preceding the sun, it is whitish-grey. The sun with the surrounding glow resembles in shape a huge comet, of which our luminary forms the gigantic nucleus, the head and part of the tail alone having risen above the horizon. This glow gradually contracts about the sun, being always much elongated on the side nearest the horizon. About midday a faint white glare alone is visible; but towards afternoon the same phenomenon as at sunrise occurs, only reversed in direction. Some moments after sunset the bluish-white heart-shaped glare forms itself; on each side, a dull brownish-red arm of light is seen stretching northward and southward along the horizon. Some minutes later, and just about when the heart-shaped bluish-white glare attains its brightest, an arc of light is formed in the eastern sky, resting on the band of light or band of glow which now surrounds the horizon. This arc resembles in shape a small segment of a rainbow, and rises to an altitude of about 50° to 60°. Inside there seems to be a blank or want of light. Meanwhile the secondary glow is beginning to form in the west at an altitude of about 40°, and just over and round about the bluish-white glare. A few minutes later and the whole sky seems to show a feeble illumination, while the arc of light in the east rapidly disappears. The secondary glow has now reached a deep rosy-red tint, as before described; at first seemingly floating some degrees above the horizon, but gradually sinking lower and acquiring more uniformity of texture. The regions near the horizon pass through bright yellow to dark orange very deep in tint. About 45 minutes after sunset this secondary, and most magnificent glow, contracts towards the point of sunset and settles on the horizon line. As soon as this happens, the arms of light and general luminosity of the sky mentioned above entirely disappear. Stars of smaller magnitude become better defined, and the twinkling of the stars in general seems to become more decided. Everything settles in for night and darkness. When, lo! the seemingly expiring glow in the west is again seen to increase; about 45° above the horizon a similar dull glow is forming, which increases in like manner as the secondary glow. The pale glow over the horizon assumes a peculiar greenish-yellow, which gradually deepens into a muddy fiery red. A *third* glow appears, and behaves much

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[*] 'English Mechanic,' June 6, 1884, p. 296.

the same as the secondary glow, only its general tints seem duller. This glow has but little reflecting influence on the now rapidly-darkening sky, situated further eastward, which produces a strange effect of contrast. It seems to me that this glow may be caused by reflection from dust haze situated at a greater altitude than the dust haze of the secondary glow. In other words, there are two layers of dust floating in the upper strata of the atmosphere, but at very different altitudes; while in between them there can be but little diffused dust floating about, hence the interval between the glows."

M. Pelagaud writes, on April 14, 1884, from St. Paul, Bourbon, as follows:—"Nouvelles observations d'illuminations crépusculaires à l'île Bourbon.[*] Our twilight glows have passed into a new phase, the intermittent phase. Some days they almost entirely disappear and are represented only by a slight phosphorescence; then the next day they recur with renewed intensity.

"On April 4, they were admirable and as beautiful as ever; and again on April 11; but they did not have the same arrangement as at first. Then they consisted of three large tricoloured zones, which extended from the west to the zenith, and were sometimes separated from one another by three wide coloured bands of blue sky. Now they are usually glories which shoot up in divergent rays to 50° or 60°. At 7 or 8 minutes after sunset a pale luminous lilac spot begins to be defined at 10° or 12° above the point where the sun has disappeared; its diameter may be about 15°. To the right and left are two smoky walls like the smoke from a large town, seen as a transparency against the red horizon of the setting sun. Then these walls vanish, the lilac spot disappears; and just above it there begins to appear, about 15 minutes after sunset, a luminous haze of scarlet purple and crimson hue, and of a discoidal form, which gradually widens to 15° or 20°, increasing in intensity of lustre, and, soon after, shoots upwards the great rays above-mentioned. At the moment when these rays appear the lower margins of the disc retract, and take the form of an arc of a circle resting on the horizon; but all the margins are indefinite. Sometimes obscure rays are observed between the bright ones, especially on the south side. All this lasts a quarter of an hour or 20 minutes, and then gradually fades away until, at about 6.35 or 6.40, there remains only a yellow band on the horizon, which also soon disappears. I am induced to think that the phenomenon is electrical. Cyclones have been unusually prevalent, and these exclude all hypotheses as to the suspension of fine particles in the higher atmosphere for upwards of six months. On the other hand, I have seen (once only, it is true) a roseate haze start from a very high cirro-stratus."

Prof. von Bezold,[†] of Munich, observes that:—"Besides the extreme brilliancy and depth of colour some other points may be specified as abnormal:—

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[*] 'Comptes Rendus,' xcviii., pp. 1301, 1302.

[†] 'Zeitschrift für Meteorologie,' 1884, p. 72.

1. "While, in ordinary conditions, after sunset or before sunrise, an increase of brightness is observed in the neighbourhood of the sun (near the horizon), having the form of a weakly illuminated disc with a spot above the sun for its centre, this appearance has lately been far more striking than usual.

2. "Immediately before sunrise, or after sunset, the illumination of the sky, particularly with a hazy atmosphere, turned to a peculiar yellow, often of a sulphur colour, such as is not seen in ordinary twilights.

3. "The illumination of the whole sky was unusually diffuse, so that the boundary of the so-called earth shadow could never be clearly recognised.

4. "The first purple light, of which the maximum appeared from 30 to 35 minutes after sunset between January 8th and 13th, was much more extensive and less well defined than usual. Whereas usually it appears as a defined disc above the bright yellow segment, so that its lower part appears to be covered by the yellow, and whereas it very seldom reaches to the zenith and never beyond it, in the recent twilights the greater part of the sky was frequently flooded with purple light.

5. "Quite abnormal, too, was the extent and intensity of the second purple light. It reached its maximum about 70 or 80 minutes after sunset, as in a normal twilight, but was incomparably brighter, and much more strongly coloured."

F. A. Rollo Russell

PART IV., SECTION I. (B).

Proximate Physical Cause of the Unusual Twilight Glows in 1883-4.

By the Hon. Rollo Russell.

The condition of atmosphere most favourable to the visibility of the complete and undisturbed fore-glows and after-glows of 1883–4 was freedom from clouds, and a transparent lower air. Any haze of an ordinary kind in the upper or lower air greatly interfered with the characteristic phenomena. Also when the unusual haze which accompanied, and, as we shall show, probably produced, these phenomena, was present in sufficient quantity to cause an appearance of mist on the horizon and to obscure the sun before setting it was unfavourable to the observation of fine displays.

This latter condition prevailed in Surrey on November 23, 24, and 25, 1883, the sun vanishing in a misty film of striæ resembling indistinct cirro-stratus. The sunset on those days was followed by appearances detailed in Section I. (A), pp. 152–178. The sun as it sank into the haze was peculiarly white, but not well-defined, being surrounded by a kind of halo and having a green light above it. This haze seems to have been very similar to that which, three months earlier, obscured the sun in the tropics near the equator; while, further from the equator, where the lofty haze was less dense, brilliant after-glows were seen. Several observers in the Atlantic, Indian, and Pacific Oceans, described the sun as disappearing at some altitude above the horizon.

The white haze described in Section I. (A), when distinctly visible as a stratum at a great altitude, was favourable to the production of fine displays, and preceded the most brilliant and extensive after-glows. At Honolulu the sky was seen to be covered with a very light wavy mist, and in many parts of the world a lofty striated haze was seen previous to the red illuminations of the sky. In England it was noticed by several observers. In Italy, in January, 1884, the white gauzy veil after sunset was the surest prelude to a display. In Europe, as stated in Section I. (A), the stratum in full daylight was white, apparently nearly motionless, and almost invariably arranged in parallel streaks stretching from about south or south-west to north or north-east. It gave the impression of lying at a very great altitude; and this impression was strengthened when it was found that, for more than two months, through all kinds of weather, it persistently preserved its peculiar character and apparent immobility, even when high cirrus clouds were moving rapidly; that after sunset and long after the highest clouds in the neighbourhood had lost their colour, it seemed to be illuminated by direct sunlight; that it was accompanied by the appearance of a corona round the sun during the day, much better visible at altitudes of 10,000 feet than lower down;* that the streaks of which it was composed converged to a radiant point much below the horizon, and gave the impression of being really parallel, and that though the duration of the morning and evening glows gradually diminished, the stratum did not, for some months, reach a level affected by the currents of the cirrus region.

We may thus fairly conclude that a stratum of matter, not usually discoverable, was present in the upper atmosphere of a great part of the globe during the autumn and winter of 1883–4, that is, during the period when the remarkable glows were conspicuous. The first remarkable sky colorations of long duration were observed at several places in the Indian Ocean on August 26 and 27, and rapidly extended in various directions, but chiefly W. and S.W. Lines drawn from place to place in the order of dates, if prolonged backwards, meet somewhere near the Strait of Sunda, which must therefore be taken to be the place of origin of the cause of the glows. On the same days the ocean was covered to a long distance, especially westward, with a very fine dust, consisting chiefly of pumice, floating lightly on the surface; and this fine dust was noticed to fall from the sky as far as 1,175

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* FOREL, in Switzerland ('Comptes Rendus,' xcix., p. 423); and HEYDE, at Kailong, Lahoul, India (MS.); and BACKHOUSE ('Nature,' August 14, 1884).

English miles west of Java on August 28, and at 3,754 English miles W.N.W. on September 8. This also, by the order of dates, showed an origin near the Strait of Sunda. A whitish or yellowish sky and a blue or green sun were seen on the same days, August 26 and 27, and first in the neighbourhood of the Strait of Sunda; so that all these phenomena depended on some agency at work in that quarter. The widely-extended-fall of dust from this yellowish sky, and the long-continuance of the haze in the upper regions, make it reasonable to assume that the lofty stratum consisted of exceedingly fine dust, projected by some cause to a height above that of the known atmospheric currents.

The great eruption of Krakatoa on August 26 and 27 appears to be an adequate cause. And its potency can hardly be doubted when we compare its effects with those of two other years of great volcanic activity, namely, 1783 and 1831, which were distinguished by similar coloured suns and red after-glows.* The redness of the sun in 1783, which was more frequent than the moon-like appearance, may be attributed to the density of the volcanic haze in the lower and intermediate air; and this condition had its counterpart in 1883 in the Indian Ocean, wherever the lower as well as the upper air was unusually hazy. The haze which caused the blue sun in the tropics did not lose its properties as it spread northwards; for in Europe the sun appeared whiter than usual at low altitudes, the moon was occasionally slightly greenish during the night, and the stars were less yellow and more green. As in the tropics, the red after-glows accompanied the red-arresting or blue-sun haze, when not too dense. If the influence of the lower atmosphere could have been eliminated, there can be little doubt that a greenish tinge would have slightly predominated in the sun half an hour before sunset. In China, for example, the sun was seen green in November, and the fiery sunsets took place soon after.

In order to realize the effects of absorption (so-called) at heights beyond the paramount influence of the lower air, let us place ourselves in imagination in the middle of the lofty dust-stratum, and observe the appearance of the sun as it approaches the horizon. When it reaches a point at which it is shining through a maximum length of the stratum, it must appear greenish or bluish;† then, as it sinks lower, the proportion of intermediate lower air increases, and the solar disc may appear white,† an equivalent portion of the violet end of the spectrum being now arrested. Still lower it will appear yellow, orange, and red in succession, as the lower and more vaporous strata relatively increase in effective power, these colours being far more brilliant than we are accustomed to see at low levels, owing to the smaller

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* See Section V., pp. 388 and 396.

† For the stratum is supposed to consist of particles similar to those which caused the blue sun in the tropics. The real colour of the sun at great altitudes is here assumed to be white, though, according to Prof. LANGLEY, it approaches violet.

proportion of gross vapour, dust, and impurities, and the greater length of intervening air. The red colour of the sun, when seen at sunset on a clear day from a mountain top, is brighter and purer than when seen through a dense mist at midday to leeward of a large town which burns smoky coal. The red tints reflected from the loftiest Alpine summits and high clouds at sunset show more brilliancy than those reflected from lower clouds, partly, no doubt, owing to the contrast of the increased darkness and the absence of other colours in the intermediate air.

Now, instead of occupying in imagination the position in the middle of the dust-stratum where these changes in the sun's colour would become apparent, let the observer watch the stratum from the surface of the earth from a few minutes after sunset. If the stratum be supposed to contain a multitude of small colourless particles, and to be only moderately dense, the colour-changes before observed in the solar disc will be seen by reflection in the vault of the sky, and will only be masked by the blue effect of the ordinary sky particles where the white surfaces are seen least obliquely, as overhead. The maximum effects of colour will occur where the influence of perspective, unimpaired by atmospheric opacity, is greatest, and the light strongest in comparison with that of the intermediate air. The whole sky will be illuminated by diffuse reflection of the sun's rays, if the reflecting particles be opaque, and the order of colours will be uniformly greenish-blue, green, white, yellow, and red in succession, each colour appearing first in the east, and passing over to the west. Even if the surfaces were tinted, somewhat similar colours would be observed, as may be seen when a bright yellow or red sun, in setting, tinges all objects with the same hue. This effect is especially noticeable when the air is clear after a heavy shower, and when diffuse light from the sky is intercepted by clouds.

But, do these contingent phenomena correspond with what actually took place over England in the glows of December, 1883? On some few occasions the resemblance was close, but usually the strong coloured illumination was confined to a part of the sky between the horizon, near where the sun set, and the zenith; and frequently the sky towards north and south remained of the usual blue colour. From December to the beginning of February the arc of colour contracted in area, and occasionally the luminous cloud shaded off rapidly into deep blue at the edges. The luminosity of November 9 was sharply defined, but on that occasion the matter concerned seemed not to be spread over the sky, but separated into distinct cloud-like masses. At the end of November and beginning of December, the whole sky was illuminated with yellow and red, in the manner that might be expected on the foregoing assumption. The blue and green did not, however, appear clearly in the east before reaching the west, probably owing partly to the amount of bright and mixed colour in the still strongly illuminated intermediate air soon after sunset. This general redness, seen in the first fortnight of the remarkable series of after-glows in

England, always occurred when, in a favourable light the white layer of matter was noticed to be particularly dense, and never occurred when the layer was previously almost invisible; though brilliant glows might then be seen between the western horizon and the zenith.

The hypothesis, then, by which the glows were assumed to have been wholly due to the action of small *opaque particles* of mineral dust distributed in a stratum of still smaller particles, fails to account for the moderate extent and peculiar character of the coloured arc on most occasions. It fails to account for the opaline whiteness of the sheen soon after sunset, for the great brilliancy of the orange and red colouring in the late twilight, and for the metallic cast of the colours.

But let it be assumed that instead of ordinary opaque particles of matter, most of the larger particles in the stratum consisted of glass-like laminæ or very thin fragments and spherules, and the peculiar characteristics of the after-glows admit of fuller explanation. The small dust of the glassy particles must be imagined to lie in all kinds of positions and at all angles, according to their form and centre of gravity. The majority would presumably be horizontally disposed, or, if curved, would have their convex side downwards. Whether lying horizontally or hanging vertically, the situation directly above the observer would clearly be unfavourable for reflection vertically downwards. Some time after sunset, the maximum brightness would take place between the observer and a point vertically above the sun, by regular reflection from smooth horizontal surfaces, and the part of the sky next in brightness to the western arc would be the east, where the effective reflection would be from nearly vertical surfaces and from spherules, for water particles in clouds near the eastern horizon are strongly luminous at sunset, and vitreous particles would reflect in a similar manner. The sky in the north and south would be little affected by direct reflection from such particles, and might sometimes appear greenish-blue by repeated reflection and scattering of light from beyond through the red-arresting stratum, but close to the horizon a certain amount of redness, less than ordinary, might appear, owing to scattering and sifting out of blue rays by the lower strata and to secondary reflection by ordinary dust. A greater density and preponderance of spherules and fragments, would cause the whole sky to be bathed in red or orange, as it is occasionally with extensive cirro-stratus. For, when a thin high ordinary cloud spread over the sky except in the direction of the setting sun, is illuminated after sunset, the spherules of which the cloud is composed will reflect the sun's rays in every plane, so that a red colour is observable in all directions.

The failure of the red glow to appear overhead, except when the stratum was at its densest, would be due (1) to the less favourable angle for reflection, (2) the less depth of matter in the line of sight, and (3) the greater intensity of the blueness of the sky which would neutralise the red. A Nicol prism revealed to

Mr. AITKEN[*] the red light overhead before it appeared in the west after sunset, even when quite invisible to the naked eye.

Now, let us examine the grounds on which the assumption that the lofty stratum actually consisted of glassy laminæ may be based.

We have, above, stated the reasons which favour the theory that the stratum had its origin in the projection of a mass of fine dust from the volcano in eruption in the Strait of Sunda, when the remarkable long-enduring sky-illuminations were first observed. All reports agree in stating that the fine dust collected at great distances from the volcano consisted chiefly of fragments of pumice blown into very thin transparent plates; and Mr. STANLEY[†] found that the dust which fell on the *Arabella* at 1,127 English miles west of Java Head, on August 28, contained small irregular plates of pumice, a vast number of which seemed to be broken shells of pumice bubbles, of thicknesses varying from ·001 to ·002 mm. Many of these small pieces were nearly square and curved, but there are types of all forms incident to fracture. A large number of thin plates are thicker on one edge than on the others, having the form of wedges. The volcanoes of Java produce these thin glassy plates of pumice through enormous steam pressure in the interior and the sudden expansion of the masses blown out into the atmosphere.[‡] Professor BONNEY found the "glass foam" of Krakatoa to be more expanded by internal steam pressure than the glassy dust of the Andes. The fragments of bubbles would, therefore, be thinner and finer than those which fell 65 miles away after an eruption of Cotopaxi, of which Mr. WHYMPER found that from 4,000 to 25,000 were required to weigh a grain. Those which did not fall so soon would of course be far thinner and smaller. Messrs. MURRAY and RENARD[§] have found by a microscopical examination of Krakatoa pumice that its fracture has probably been owing to a tension like that observed in Rupert's drops. The particles have ragged edges which show disruption of a vacuolated or bubble-like structure. A rapid cooling and decrepitation must take place in the passage of the heated pumice masses through the air; and thus a vast quantity of extremely finely-divided matter be carried into the higher atmosphere.

Crystals in granitic rocks and some lavas contain great numbers of excessively minute cavities, often filled with liquids. It has been estimated that in some instances the number of these minute liquid cavities amounts to from one thousand millions to ten thousand millions in a cubic inch.[||]

Dr. FLÖGEL's researches[¶] on the dust which fell on May 21, 1883, on board the *Elisabeth,* near Sumatra, also showed that by far the greater part of the ash is a

[*] 'Proc. Roy. Soc. of Edinburgh,' June 2, 1884.

[†] 'Quar. Jour. Roy. Met. Soc.,' vol. x., p. 187.

[‡] BONNEY, 'Proc. Roy. Soc.,' 1884, p. 124.

[§] 'Proc. Roy. Soc. Ed.,' Feb. 4, 1884.

[||] JUDD, 'Volcanoes,' pp. 61–62.

[¶] 'Met. Zeitschrift,' vol. i. (1884), p. 81.

colourless glass, which seems to be broken into all imaginable forms. All these glass fragments contain either innumerable air bubbles or they are full of needle-like small crystals, or they combine these two.

The thickest fragments of burst bubbles and the heavier particles fell at or within such distances as the *Arabella* was from Krakatoa ; but the lighter and smaller particles were carried much further, and would remain longer in the air in proportion to their minuteness. Besides this, the proportion of glassy matter, which was the lightest of the ejected products, was found to increase continuously with the distance from Krakatoa.

As the pumice ejected by the Java volcanoes consists of an aggregation of vast numbers of minute glassy vesicles, an unknown proportion of these vesicles would burst on suddenly reaching a much lower pressure at a great height in the atmosphere ; many, however, might still preserve their vesicular form, owing both to the tenacity of their substance and to the condensation of the steam within by great exterior cold. The sudden cooling of the exterior crust of a large pumice stone prevents the disturbance of the honeycomb structure within, and similarly the cooling of the surface of a very small particle may prevent the diminution of pressure from affecting the minutest bubbles in the interior. We may therefore suppose that the small amount of vapour or gas which had existed within at a very high temperature and pressure was, by cooling, condensed to a very small bulk. Some of these small particles would accordingly float in the upper air as microscopic, nearly vacuous, perfect balloons.

The extreme tenuity of volcanic dust has been proved on this as well as on other occasions. No watches, boxes, or instruments were tight enough to exclude it from their interior.[*] Thus we may conclude that both in the form of vesicles and of fragments of vesicles, an immense volume of glassy pumice dust of microscopic and ultra-microscopic minuteness was projected into the atmosphere on August 26 and 27.[†]

Now, what would be the order of phenomena seen from the surface of the earth, assuming the existence of a stratum thus composed at a height of from 80,000 to 120,000 feet above the surface of the earth ? The general tendency of the matter being to deprive the sun's rays of a portion of their red, as shown by observations at Batavia, Ceylon, Labuan, Cape Coast Castle, etc., the colour of the sun some time before setting, when shining through a great length of it, would appear green or blue, or else less yellow and red than usual, according to the density of the matter. When the stratum was less dense, as it was after the lapse of several months, the sun would only be rather less red than usual at and before sunset. After sunset, the excess of

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[*] See the *Elisabeth's* experience (VERBEEK'S 'Krakatau,' p. 89). See also WHYMPER'S experience on Chimborazo during the eruption of Cotopaxi. BONNEY, 'Proc. Roy. Soc.,' 1884.

[†] Mr. GOODWIN, of Kingston, Canada, found the most characteristic objects in residue from snow on January 13, 1884, to be minute transparent granules scattered in thousands over the field of the microscope.

green rays produced by the passage of the solar light through the stratum would first be reflected from the suitably disposed particles east of the observer; but these would be partially neutralised by transmission through the lower air, and by the ordinary reflection of reddish rays from dust-particles in the middle air, where the sun would be much earlier setting than in the stratum. Then the sky overhead would turn somewhat green, but the strong blue colour of the still illuminated upper air below the stratum would mask it. In the west, the green would in a few minutes become visible, yellow would follow, and orange or pink next, owing to the greater persistence of the rays of larger wave length; but as long as the whole air below the stratum was strongly illuminated by the ordinary twilight, the effects would not be very conspicuous. The first colours would be bright only in the west, where horizontally floating pumice particles would reflect the sunlight more directly towards the observer. Then a reddish glow would appear in the east, caused by the reflection of sunlight from those of the particles which were nearly vertical, from small irregular fragments, and from spherules. As the sun sank, this redness would pass across the zenith, where it would be often masked by the strong blue sky colour, and would then become conspicuous towards the western horizon, reflecting the last rays of the sun setting at its level. The red arc would sink slowly on the horizon, becoming deeper red owing to the sifting out of the more refrangible rays by the lower air; but, when still at some height above the horizon, the green portion, now below the horizon to an observer on the earth's surface, but which would not yet have sunk out of sight from a point of view at the level of the stratum, would be sending its rays eastwards, and would affect the dust particles at that height with a tinge of green, or with a mixture of rays producing a dingy colour compounded with the blue of the sky. The next colour to appear in the east opposite the place of sunset would be yellow, by reflection from the reflecting arc in the west, but this, again, would tend to become reddish as seen from the earth, owing to the great length of air through which it had passed. When, after crossing the zenith, the yellow appeared in the west, it would be tolerably bright, but would be modified by the fact that the under surface of the stratum would be receiving different shades of colour from the differently coloured bands of the first arc overlapping one another, and the tendency would be towards orange, both from the rapidly growing redness of the first arc as the yellow band sank out of sight from the point of view of the high level, and from its own descent, and consequent interference of the lower strata. The next colour in the east would be red from reflection of the last red band of the first arc; and this, too, would soon appear with greater brilliancy in the west, and would deepen in tint as it followed nearly the course of the first arc. With a deep red on the western horizon, the second after-glow would end. The fainter and less defined character of the second glow would be owing to its being a reflection from the first arc of glowing haze, and not of direct sunlight.

Such might naturally be taken as the succession of phenomena which would occur by transmission through and reflection from a stratum composed of small reflecting dust, partially transparent and partially opaque, or else consisting of a mixture of transparent spherules and fragments, having the qualities described; and such, on the whole, was their normal course, though there were differences from day to day, depending on the density and other qualities of the film, and on the distribution of clouds and vapour. The yellow was, perhaps, less conspicuous than might have been expected; but we must remember that the red would of necessity be the strongest colour near the horizon in ordinary conditions of the air, for, a white light near the horizon becomes reddish by transmission, and that the sun, when shining most on the under surfaces—that is, just before sunset at the high level—would be red. Before sunrise the yellow frequently covered a large part of the sky, and lasted many minutes, succeeding the red in the primary and secondary glows. The succession of colours, which took place slowly at the high level, appeared in a corresponding manner on the lower clouds in November and December. Small detached cumuli overhead turned green, while the sky above them was first blue, then pink or orange, showing that the green light in the west still shone on their lower surfaces, forming, as it were, their secondary glow, while the sky above was reflecting direct sunlight. Sometimes they remained pink for an hour or more, reflecting the light of the reflected red on the horizon, and unaffected by the colours too high above the horizon to shine on the under surfaces. This persistent tint is evidence of the mere preponderance of certain transmitted parts of the spectrum in producing bright colorations, and of the power of the lower stratum of air to change the preponderating transmission from green to red. The amount of colour, when there was little redness left on the horizon, even probably at the level of these cumuli, showed the effect of a small quantity of light on clouds in a dark sky. If the stratum of dust had been of a density comparable to that of light cumulus, and more transparent, the illumination of the secondary glow would have been much stronger than it was.

The striking predominance of red in the fore-glows and after-glows was owing, first, to its greater contrast with the blue sky; secondly, to the greater surrounding darkness when it appeared; thirdly, to the lower position of the sun favouring reflection from the lower surfaces of the stratum to the earth; and, fourthly, to the red being the last colour, and therefore less mixed with others. To these may be added the better penetrating power of red through the lower strata of the atmosphere.

In several descriptions of the after-glows the red coloration is described as appearing in the west and then extending upwards towards the zenith; and this was frequently observed in England. In the magnificent after-glow of November 9, in Surrey, the colour grew upwards both in the primary and in the secondary illumination. As a matter of fact, the red light must have been passing from east to west, but the position of the part of the stratum situated over the western horizon would, owing to perspective and the more favourable angle for regular reflection from most of the particles at a small altitude above the horizon, cause the faint beginning of the glow from the lower surface to appear to the observer before a stronger reflection would manifest itself at all nearer the zenith. Frequently a certain amount of redness appeared between 10° and 40° above the horizon some minutes before the whole western sky was illuminated; but on other occasions the red reflection moved steadily from the zenith to the horizon, and before sunrise on the days of maximum colour it rose from near the horizon to the zenith and passed westwards, leaving the east of a light straw colour or green.

On some occasions the southern, and on others the northern, part of the sky was more strongly illuminated than the rest. In many of the observations in the southern hemisphere this peculiarity was noted, which would merely seem to indicate a greater density of reflecting matter in one direction or another. When, after some months, only the finer particles remained, the arc of colour was seen more regularly extended over the place of sunset, while the sky, towards north and south, remained blue.

The capability of vitreous surfaces to reflect powerfully the light of the setting sun is experimentally verified by the reflection from distant window-panes eastward of an observer, as they glow with an intense brilliancy hardly distinguishable from that of the sun itself. The character of the appearance quite coincides with that of the after-glows, though these were, of course, softer and less dazzling. The Crystal Palace, viewed at a distance of 8 or 10 miles at sunset, resembles a great fire, and small windows, at shorter distances, flame out with surprising intensity. The heliograph is an example of the use to which vitreous and metallic reflection has been put in communicating through great distances. When it is remembered that the after-glows took place when the intervening air was no longer in sunshine, but in deep shadow, their brilliancy is by no means disproportionate. Panes of glass suspended in mid-air westwards would certainly display a similar luminosity from their under surfaces. In like manner a rippling sea or lake reflects dazzlingly the rays of the setting sun, the waves presenting to them a great variety of inclinations. That a thin and previously almost invisible film of transparent particles can reflect conspicuously the red light of the setting sun is frequently proved by light cirrus streaks floating at altitudes between 30,000 and 40,000 feet. The much greater brilliancy of the coloration in the west than in the east in the after-glows would be due partly to the position of the fragments, for, the great majority would be floating horizontally, but the same effect takes place with the spherules of water in light clouds.

Taking the refractive index of pumice as about the same as that of glass, viz., 1·50, the small laminæ would show, more or less strongly, the colours of thin plates, if tolerably equal in thickness, at thicknesses less than about $\frac{1}{7000}$ of an inch; but, beyond about $\frac{1}{300000}$ of an inch, would not reflect much light falling upon them, and beyond $\frac{1}{2000000}$ of an inch would practically reflect none at all.

Probably the particles varied greatly in thickness, and would in white light reflect a variety of colours, so that the general effect would be colourless or white. If an effect of coloration had been due to interference, a part of the sky high above the horizon would not quickly have changed in regular order from red to yellow and green, as it did, before sunrise and conversely after sunset. The colours of thin plates may, however, have had something to do with the opalescent effects occasionally noticed above the setting sun and after sunset, and the persistent faint pink and green tints sometimes succeeding the brighter colours before sunrise.

On the theory of mere reflection of the sun's colour by vitreous surfaces as the cause of the twilight phenomena, we must still assume the particles to have been not less than about $\frac{1}{300000}$ of an inch in thickness, in order to reflect much light, coloured or white, and since particles which fell on the *Arabella* at about 1,140 English miles west of Krakatoa were between $\frac{1}{12000}$ and $\frac{1}{25000}$ of an inch in thickness, the probability is that the mean thickness of the much finer particles in the glow-causing stratum lay between $\frac{1}{25000}$ and $\frac{1}{300000}$ of an inch. Particles thinner than $\frac{1}{300000}$ of an inch would not be effectual in reflection, except, perhaps, from their edges, but might absorb some portion of the spectrum. In this way the light reaching the reflecting particles may have been altered by transmission through the smaller dust. As before stated, the microscopic examination of pumiceous matter reveals remarkable facts regarding its constitution. High microscopic powers show in a slice of lava cloudy patches, which can be resolved into distinct particles only by still higher powers.* These particles seem to consist of very minute crystals or embryo crystals. The mass of matter ejected from a volcano like Krakatoa and disseminated in the upper air may consist of similar vesicles or fragments blown out without the opportunity of conglomerating in the liquid state, and the size of the particles would correspond with that required to produce the atmospheric effects.

The after-glows of 1883, when at their maximum, presented certain features which indicated that they might be due not wholly to transparent reflecting surfaces, but partly to small dust of a more ordinary kind. Thus the visibility of the glow over a large part of the sky, and its occasional appearance even at the zenith, might be produced by diffuse reflection, and not by the regular reflection of vitreous particles. These non-transparent particles might be much smaller than the regular reflectors, and still reflect any light which fell upon them;† while even smoke has some reflective power in strong light. But opaque dust is not necessary, and would hardly have been adequate to produce all the observed effects; and here, again, we may note that thin and lofty clouds reflect red light after sunset, from all parts of the sky.

The question of the floating power of small particles, such as those which probably composed the haze in the present case, is dealt with in Section VII., p. 441.

The capacity of the stratum largely to reflect light of all colours is shown by the change of colour of that part of it which was overhead, from rose tint to pink, orange, yellow, and finally white, just before sunrise, and by its occasional appearance

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* JUDD, 'Volcanoes.'

† FARADAY, 'Researches in Chemistry and Physics, Bakerian Lecture, 1857.'

as a white rippled haze in daylight, soon after sunrise and before sunset, in England. The green colour never appeared overhead just before sunrise, probably owing to the masking effect of the blue sky, which was then strongly illuminated. The sky is at all times much greener towards the horizon than overhead, where there is not a sufficient thickness of lower air to cut off the more refrangible rays.

A very interesting consideration is suggested by the disappearance of the white stratum in full daylight in most parts of the sky in November and December, though cloud-like in apparent density an hour before sunrise. It seems that as long as light shone upon a veil of dust at a great altitude, and not much upon the air below it, the greater part of the matter which makes our sky appear blue was ineffective; but when the sun's rays traversed the whole intervening region, the blue-scattering particles became a veil for the white above. It is known by observation on the high Andes that, at 20,000 feet, the blue of the sky tends to become dark blue or black, thus showing that a large proportion of the colouring matter lies below that altitude. Thus we may assume that nearly the whole of the matter concerned in producing the ordinary blue sky was below the stratum, and if this assumption be a true one, the disappearance of the white stratum in full daylight is explained.

The silvery glare in the western sky soon after sunset, with its remarkable lustre, would be produced by regular reflection from glassy surfaces, while the sun as viewed from that altitude was still several degrees above the horizon. Almost everywhere the sky tints were noticed as strange, unearthly, ghastly, weird, or awful, and not resembling the beautiful sunset colours so frequently tinging the upper and lower clouds. In accounts of the phenomena from places widely separated, and from August 26, 1883, to January, 1884, we have remarks on the colours of the sky as resembling lead, copper, brass, steel, and silver. Common dust would not, so far as we know, produce these metallic colours.* During 1885 there was not one sunset or sunrise which exhibited any of the strange tints seen in 1883 and 1884 in England, and, as a rule, the sunsets even when clear were almost colourless. Taking all the evidence into consideration, the twilights of 1883, 1831, and other years seem to have owed their specially brilliant character to the minute subdivision of pumiceous matter by the disruptive force of steam at high pressure, and for this reason some submarine volcanoes may have produced atmospheric effects disproportionate to their size and altitude.

The colours of the western sky, 20 minutes after an ordinary sunset in England, are commonly as follows: dusky brown near the horizon, above that dull red, reddish or orange, pale yellow, dull greenish-blue, blue; these colours being either dull and ill-defined, or very pale and clear. The colours are very seldom anything but pale and ill-defined when there are no clouds, and often there is scarcely a trace of anything but grey and blue. At the maximum of the glow phenomena the above

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* KIESSLING experimentally produced similar metallic tints with transparent minute particles.

order was nearly reversed, the colours were far more vivid and prolonged, and of an unfamiliar character. There is no record of an order of colours corresponding in completeness to that of the glows of 1883.[*] VON BEZOLD's description of normal twilight does not at all accord with what was then observed. In these glows the ordinary colour on the horizon, when visible, was perhaps less bright than usual. No dark segment like that described by VON BEZOLD appeared in the east. No feebly illuminated circular disc, sinking fast, was observed. The after-glow occurred when the sun was 4° or 5° below the horizon, and sank only slowly. No "second dark segment" appeared in the east, unless the absence of colour other than blue, and the gradually increasing darkness, may be described as such. A slight re-illumination of the east occurred when the first after-glow had sunk rather low, and then this re-illumination appeared conspicuously in the western sky as the secondary after-glow. The differences between the abnormal and the normal twilight may have been largely due to the difference of altitude of the reflecting particles concerned in them.

It may be desirable to compare the order of reflected colours from common clouds in an ordinary sunset with that observed during the twilight glows.

On January 31, 1886, the air was clear in the afternoon, with a strong west wind and a blue sky, flecked with a few small masses of cumulus. The general state of the air at sunset was not unlike that of November 9, 1883, except that there were only a very few clouds on that occasion. But on January 31, 1886, the condition of the upper air was normal, and therefore served well for comparison with the strange developments of colour on November 9, 1883. The sun was nearly white about 25 minutes before setting, then light yellow, yellow, orange, and red in succession, setting behind a very low and slight bank of clouds. About 10 minutes before sunset the small cumuli in E., N., S., and W. were light yellow or buff on their under surfaces, and gradually turned into a pinkish-yellow and pink or red in correspondence with the sun's colour as seen from the earth. They lost their colour just after sunset, showing their low altitude. A long, narrow cloud in the west was much brighter directly above the place of sunset than towards north and south. The sun set at 4.45. At about 4.50 the little cumulus masses in the east began to turn ashy green,[†] in correspondence with the brighter and clearer green of the sky above the place of sunset. At about 4.56 the eastern sky, beyond the little clouds near the horizon, began to show a slight, dull, pink flush; and this grew up, and at about 5.7 showed itself on the western horizon, and then the greenish colour of the cumuli eastwards was succeeded by a pale pink which attained its maximum with the maximum redness on the western horizon, which was never more than a pale and weak illumination.

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[*] See LIAIS's account of a voyage to Rio Janeiro in 1858, 'Comptes Rendus,' t. xlviii., p. 109.

[†] The "Leichenfarbe" of observers in the Alps, where the high snowy tops turn red soon after sunset, then ashy pale, and then again red (see DE LA RIVE, 'Bibliothèque Universelle,' xxiii., xxiv., 1839, and NECKER, 'Annales de Chimie et Physique,' 1839.)

There was a slight pinkish light still in the west at 5.30, and a very faint projection of pink rays. The deep blue sky overhead, at 5.20, shaded towards the west into blue with the slightest visible tinge of purple. The succession of colours, therefore, with cumulus is not unlike that in the sky during the strange glows, but the duration is very much shorter. In both cases the phenomena seem to be due mainly to reflection of the sun's changing colour in setting, and next, of the light reflected by the sky in the west, when the rest of the sky is already darkened.

In the case of a high stratum of gauzy cirrus which occasionally, though rarely, covers the sky, some changes of colour occur similar to those of 1883, though the duration of the colours is much shorter. Thus, on December 16, 1885, at Richmond, in Surrey, the eastern sky was suffused with red 40 minutes before sunrise, and afterwards with yellow; but the green and the metallic tints were absent, and the areas of colour were far less definite.

Cirro-cumulus covering the sky, with the exception of a clear space in the west, at sunset, produces splendid effects when the sun sets clear red, the sky appearing like a sea of fire, but the condition is of short duration.

A possible cause of the pinkish light which is occasionally seen in the sky after sunset in summer and autumn in Switzerland, may be the presence, at a high level, of Sahara dust, which could travel the distance in a very short time, and is known to affect the atmosphere far out in the Atlantic, sometimes even to the extent of being visible and collected as dust. Off the west coast of Africa, near the Cape Verde Islands, when a certain wind blows from the land, the air is filled with fine dust, which is deposited hundreds of miles out at sea, and the sun then sets deep red, or disappears in a kind of bank at some altitude above the horizon. At the edges of the area thus affected, or where the dust is less thick, a red coloration is sometimes seen in the sky long after sunset.[*]

The red twilight of Egypt and North Africa, and on the borders of the desert, prevails especially in the summer and autumn, and appears to be caused by the rays of the sun, which has set red at the earth's surface, still illuminating the minute dust which pervades the air up to a considerable height at that season.

Arago[†] explains as follows the prolonged twilights of 1831, which accompanied the dry fog of that year:—"If the fog reflected that light, it necessarily occupied in the atmosphere, or beyond its limits, regions extremely elevated, but yet not so much as would be deduced from the ordinary calculations of twilight; which calculations, in effect, are based on the hypothesis of a simple reflection; whilst it can be proved by recent experiments, of which it is not possible here to give an exact idea, that

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[*] See Liais, in 'Comptes Rendus' xlviii., p. 109, respecting phenomena in Atlantic, July, 1858. See also Howard's 'Climate of London,' vol. iii., pp. 48, 49, 192. Also the log of the *Viola*, May 24th, 27th, 1883, quoted in Section II., 'General List,' p. 265.

[†] Arago, 'On Comets.' Translated by Gold, 1833, p. 85.

compound or multiple reflections play the greatest part in all the phenomena of atmospheric illuminations. When it is agreed that the fogs shall be considered high enough to explain from them the existence of the strong nocturnal lights which were observed in Berlin, Italy, &c., the red colour of that light, however intense it is supposed and has really been, causes no farther embarrassment to the naturalist, and I shall not be delayed by it."

On December 13, 1856, during a fall of ashes from Cotopaxi, 30 miles distant, a purple sky was noted.*

The remarkable skies of Peru and the Pacific westwards, the *arrebol* of the coast of Brazil, and other unwonted twilight colours, are noticed in Section IV., p. 342.

The following observations made in Ceylon tend to confirm the supposition that the after-glows owed their colour to reflection of the sun's setting light:—

"Neither we, nor any who have yet recorded their observations, can remember the zodiacal light being coloured green. There was the persistence of the colouring for three successive days, too.† . . .

"The sun seems to have quite recovered his brightness, and all signs of the peculiar green or bluish appearance he presented a few days ago have vanished. For the last evening or two, however, a remarkable lurid glow, as from an immense conflagration, has been noticeable all over the western sky long after sunset."‡

Thus, while the sun remained blue or green at setting—that is, from September 9 to 12—the sky seems to have been coloured green after sunset, and when the sun resumed its red colour the red after-glow became conspicuous.

"On the 13th and 14th [September], at about 7 in the evening [about an hour after sunset], the western part of the horizon was lit up by an unusual brilliant red light. It lasted for about a quarter of an hour or so, and then gradually disappeared."§

"Yesterday morning, when the sun rose a little above the horizon, it looked very beautiful, being of a soft greenish tint; and as it set, instead of the golden streaks it leaves behind, we saw only a sort of greenish light. It still continues the same."||

Other observations, however, in both hemispheres show that on several occasions the sun towards setting was blue or green before a brilliant red or orange twilight coloration. On September 3, at 7° S., 33° W., the north horizon was very red at 4 a.m., and at 7 a.m. the sun was pale blue. On September 3, at 3° 6′ S., 27° 4′ W., the haze was fiery red before sunrise, and the sun, when it appeared, was white. On September 10, at Bellary, for three-quarters of an hour before setting, the sun was green; after sunset, for fully 40 minutes, the whole western sky was lighted up by a

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* 'Nature,' vol. xxix. (1884), p. 512.

† 'Ceylon Observer,' September 14, 1883.

‡ "Star-gazer," in letter dated Pallai, September 14. 'Ceylon Observer,' September 20, 1883.

§ 'Times of Ceylon,' September 20, from Jaffna.

|| 'Times of Ceylon,' September 28, 1883.

brilliant red glow. At Poochin, on September 10, a pale green sun and red sky are reported. On September 11, in the Red Sea, the sun was green at rising and setting, and there were bright after-glows, the order of colours from the horizon being yellow, orange, red. At Madras the sky, on September 12, 1883, was of an intense reddish-yellow colour at 5 a.m., and at 5.26 a.m. the east was deep red, and the rest of the sky greenish-yellow. The sun rose at 5.50 of a bright yellowish-white colour. Thus there can be no question that a white, green, or blue coloration of the sun near the horizon was not incompatible with an antecedent or a subsequent red coloration of the sky. Conversely, in England, the sun, immediately before sunrise and after sunset, as a rule, rose and set red or orange, and yet a part of the sky was coloured green or greenish-yellow.

But, as a rule, the fore-glows and after-glows were far brighter and redder where the haze was not very dense and where the sun rose and set of the usual colour. Good observations in Ceylon and elsewhere make it plain that the sun in declining changed from blue to green and greenish-yellow, and conversely from yellow to blue on rising, so that we may fairly assume that at a great altitude, where the setting and rising sun would be shining through a much greater length of lower air, the colour last at sunset and first at sunrise would sometimes be red. In fact, it is clear that the maximum comparative influence of the foreign stratum, which tended to make the sun blue, would be exerted, not at sunrise or sunset, but some time after sunrise and before sunset, at the lower surface of the haze at the high level. On very many occasions the sun was not seen on the horizon at all from the earth's surface during the period of blue-sun phenomena, and therefore, as its last visible colour was green, it would be described as setting green. But where the view was unobstructed, and when the haze was not so dense as to hide the sun altogether before it reached the horizon, the last colour in setting was frequently yellowish-white or yellowish-green. There is no instance of the sun setting or rising blue on the ocean (where the view of the true horizon was unobstructed), and being followed or preceded by a red glow; but there are several observations recording a white, grey, blue, or leaden sky before sunrise or after sunset, when the sun appeared white, blue, or leaden. Even if the sun, as it sank to near the horizon of the high level, became obscured, as it often did on the earth's surface, by the density of the haze, the diffused light transmitted might be blue, green, yellow, and red in succession, for, its declining rays would progressively pass through a much greater comparative length of lower blue-arresting air than in setting, as seen from the surface; and the red would become manifest by reflection from elevated particles, though the sun had been seen to set green on the earth's surface. Only in the early period after the eruption, and where the haze was dense, would the red-arresting particles overcome the effect of the ordinary blue-arresting particles of the lower air in a line through the atmosphere from the high level to the setting sun.

These considerations may account for the fact that red after-glows were undoubtedly seen in a few places, when the sun, not long before sunset, had been seen blue or green. In one or two cases the effect may have been owing to the sun, after sunset took place on the earth, having passed beyond the overlying stratum and having reached, from the point of view of the stratum, a clear space in the far west as yet unaffected by its absorptive or scattering influence, whence the sun would cast its usual ruddy light on the particles at a great altitude above the western horizon. This may have been the condition producing the red illumination at Trinidad on September 2; and the fiery redness of the sky before the sun rose dazzlingly white (*Queen of Cambria*, 3° 6′ S., 27° 4′ W.), on September 3 may have been owing to the sun, before sunrise, having from that position been beyond the eastern limit of the great haze stratum. It will be noticed that usually the sky was not seen red, but white, grey, or blue before a white or blue rising sun, and after a white or blue setting sun; and the exceptions may have been due to the reasons above stated.

North and south of the path of the main body of haze within the tropics, the red glows were conspicuous.

With regard to the objection that a very large quantity of dust would be required to be spread over the upper air to produce the glows which covered simultaneously so great an extent of surface, no good ground can be adduced why very small particles illuminated on a dark background, and seen through darkened air, should not combine to produce a conspicuous effect; a continuous film, not thicker than 0·000,005 of an inch, would be sufficient to reflect a considerable proportion of white light. One cubic kilometre of fine dust spread over the upper air would produce a continuous thickness of 0·002 mm. = 0·000,078 of an inch for the whole surface of the atmosphere,[*] or 0·000,156 of an inch for one hemisphere, which is probably a greater surface than was covered at any time by the glow phenomena. And a sheet of fine cloud spread like this dust in a lofty stratum over the atmosphere would occupy, as water, a very small cubical volume, but would be capable, in a finely divided state, of producing a visibly red sky with the sun several degrees below the horizon.

The tails of comets have been calculated to be of so great a tenuity that the matter contained in a tail of 100,000,000 miles in length and 50,000 miles in diameter, if compressed, would scarcely amount to a cart-load: the matter causing the blue colour of the sky may possibly occupy a still smaller volume.[†] A strong optical effect may thus be produced over a vast space by an extremely minute quantity of matter; while the distance of the stratum from us cannot be compared with that of comets.

There appears to be very great probability that a quantity of fine dust pervading

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[*] VERBEEK'S 'Krakatau,' p. 157.

[†] TYNDALL, "Scientific Use of the Imagination," 'Fragments of Science,' p. 122. See also HERSCHEL'S 'Astronomy.'

the upper regions of the air would, according to the experiments of Mr. AITKEN, condense upon itself the vapour with which it came in contact, and that, with this augmentation in size, the particles would become visible, as they were in the twilight phenomena. In the present case, however, spectrum observations and the nature of the corona, as well as other considerations, do not support this view, as representing what actually occurred. Moreover, we have had experimental demonstration on a grand scale of the competency of dry dust to produce equally remarkable atmospheric effects. In 1783 Europe was covered with a dense dry haze for several months during the summer, and the sun was shorn of its rays during a long period of dry weather. The haze extended from the sea-level to an elevation higher than the tops of the Alps. It followed a great eruption in Iceland. Any stratum of this haze—say 5,000 feet in thickness—would probably have produced twilight effects like those of 1883 if it could have been raised to a sufficient height and the lower air had been clear. The air was too dry at that time to permit the supposition that the dust particles were loaded with water vapour. The particles do not seem to have been large enough to be visibly deposited and to be examined with a microscope. In fact, they seem in character to have greatly resembled the particles of the haze which succeeded the eruption of Krakatoa in 1883, when the dust particles were carried to a height where the dryness of the air would be extreme and where clouds are never formed.

Although we do not think that diffraction through the haze-stratum accounted, without the factor of reflection, for the series of brilliant colours witnessed in the twilights of 1883, it nevertheless played a very important part, just as it does in the case of ordinary sunrises and sunsets. According to the law enunciated by Lord RAYLEIGH,* "When light is scattered by particles which are very small compared with any of the wave-lengths, the ratio of the amplitudes of the vibrations of the scattered and incident light varies inversely as the square of the wave-length, and the intensity of the lights themselves as the inverse fourth power." Consequently, the blue rays are scattered laterally, and an increased proportion of red rays is propagated in the direction of incidence. The particles of the haze-stratum were large in comparison with ordinary atmospheric blue-scattering particles, and scattered rays of the other end of the spectrum. The remarkable phenomena of the glows therefore resulted from the inter-action of these two oppositely-working layers upon transmitted rays, with the aid of a lofty reflecting dust-cloud not usually present.

Thus we may probably conclude, that the haze which followed the eruption of Krakatoa, and produced the twilight glows, was composed mainly of very fine dust, and that this dust at a great altitude reflected the light of the setting or rising sun after diffraction through the stratum and diffraction and absorption by the lower atmosphere, and secondarily reflected again this reflected light.

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* 'Phil. Mag.,' vol. xli. (1871), p. 111.

The foregoing remarks may therefore be summarised as follows :—

1. The fall of dust, chiefly pumiceous, at great distances from Krakatoa westward, on the days following the first appearance of the red twilight.
2. The existence of a white haze at a great altitude during their prevalence.
3. The great effect produced by small vitreous surfaces in reflecting sunlight when the intervening air is darkened.
4. The failure of the spectroscope, on the whole, to indicate an increased strength in the lines due to vapour.
5. The structure of the haze, more resembling that of smoke than that of the highest clouds.
6. The resemblances and contrasts between reflection of sunset rays from thin high clouds and from the haze stratum, both in the first and the second after-glows.
7. The sequence of colours corresponding with what might be expected to be the changes of colour due to the sinking or rising sun at the altitude of the stratum.
8. Previous effects seen in years of great eruptions, especially 1831, and in places affected by an excess of dust in the air. (*See also* Section V.)
9. The extreme lightness of pumice dust and the theoretical floating power of fine particles. (*See also* Section VII.)

F. A. Rollo Russell.

Professor Kiessling's Theory of the After-glows *

Herr Kiessling has made a number of laboratory experiments largely based on the discoveries of MM. Coulier and Mascart, and of Mr. Aitken, regarding the power of dust to attach vapour to itself, and has extended his researches to the effects produced by small particles on rays of light. He states that fog consists of watery spherules, the difference in their sizes making it colourless by the overlapping of numberless diffraction rings. When only a few cubic millimetres of common dusty air are introduced into a vessel containing dust-free saturated air, a silvery transparent mist forms, and when the sun or the electric arc is looked at through this mist it appears surrounded with a bluish or greenish bright sheen with a broad reddish ring, exhibiting all shades from glowing purple to the tenderest pink. These diffraction colours appear with a peculiar metallic glare. The smoke and dust particles of the atmosphere would arrange themselves, according to their weight and size, in layers. As the sun goes down, therefore, the particles above being smaller than those below, the ring appears larger over the setting sun than under it. The lower

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* Abstracted from 'Die Dammerungserscheinungen im Jahre 1883'; see also 'The History and Work of the Warner Observatory, Rochester, N.Y., U.S., 1883-6.'

layers also absorb nearly all the light, so that the white spot appears only above the sun. He says:—"All the twilight phenomena may be explained by the action of fine equal-sized particles of dust." From his experiments he finds that the diffraction of the most strongly diffracted red rays does not exceed 25° to 30° from the direction of the sun's incident rays. The red colour, therefore, would appear at about that distance, while nearer the sun there could be no colour effect, because the rays would be passing through layers of dust of very different sizes. Within the cone of light, that is, in a line drawn to a point within 25° or 30° of the sun, the rays meet with particles so various as to re-combine the diffraction colours. The result would be a white or grey sheen. When the sun has set on the earth's surface there will be no colour effect so long as the atmosphere is strongly illuminated, on account of the general scattering of light, which prevents the action of the upper stratum from becoming apparent. The maximum effect will take place when the sun has sunk so low that a part of the upper stratum between the west horizon and the zenith is receiving rays parallel to itself; and then, the particles being of the same size, the diffracted rays will pass downwards at the same angle and reach the eye of the observer further east, already in deep shadow. From this mist zone, which is, in accordance with laboratory experiments, so transparent as to be usually invisible, coloured diffracted rays proceed, and produce first an effect of colour east of the observer, where they illuminate the lower vaporous layers, the colour becoming stronger with growing darkness; and, secondly, after about 15 to 20 minutes, an appearance of luminous colour between the zenith and the west horizon, the diffraction rays now passing straight to the observer's eye. The uncommon prolongation of the twilight by the second after-glow seems to depend on a very diffuse and uniform mist, those strata exercising a considerable diffractive power which are at the outer border of the segment reached by direct sunlight, so that rosy diffracted rays penetrate into the dark so-called earth-shadow, and light up the vaporous matter there. The second rosy after-glow, therefore, will be seen when the background, on which the very weak diffuse light is set off, is quite dark—that is, when the greater part of the atmospheric arc lighted by the sun has sunk below the horizon. The extent and intensity of the first and the second after-glow must, according to experiment, depend very decidedly on the homogeneity of the mist. When a glass vessel is filled with homogeneous mist—so that, for instance, an electric light appears as the centre of a green sheen surrounded with two red and violet rings—and a few cubic millimetres of tobacco smoke are introduced, the splendid colours are at once lost in a dirty yellowish colour, with a reddish border. [The suggestion presents itself in connection with the above argument whether the rusty colour of the moon in a lunar eclipse may not be due to the diffraction of rays which have passed through the earth's atmosphere.] Prof. KIESSLING then remarks on the absence of the defined earth-shadow, during the displays of 1883–4, noticed also by Dr. VON BEZOLD. Prof. KIESSLING concludes that only two causes, either dust or homogeneous water particles produced by the finest dust, could have given rise to the after-glows. He thinks it not at all improbable that by the sifting action of months, the dust of Krakatoa should have become so homogeneous as to account for all the effects. He has seen the diffraction rings even in cement dust sifted through fine muslin.

Although Professor Kiessling's theory accounts for the solar corona, which appeared more distinctly several months after the eruption than at an earlier date, it fails to explain points of great importance in the twilight phenomena. The glows were seen on the day following the eruption and continuously thereafter. The particles could not so early have become sorted into layers of equal-sized dust. The diffraction ring was often visible after sunset in England, but seemed to be a distinct phenomenon from the brilliant colorations which followed the paler hues of diffraction.[*] Prof. Kiessling accounts for the secondary after-glow by the reflection of the first glow; so that he assumes a capability of reflection in the stratum of considerable effective strength. But if the stratum be capable of reflecting so conspicuously the sinking arc of the primary after-glow, will it not, *à fortiori*, reflect the direct rays of the setting sun? And if a stratum existed of density sufficient, as we have seen, to make the sky appear overclouded at certain stages of the twilight, we cannot avoid the conclusion that this stratum would be capable of strongly reflecting the red light of the setting or rising sun, the intervening air being deprived of its masking glare by the earth-shadow. Now, the time at which the after-glows appeared corresponded with the period after sunset at which the diffused matter, from other considerations respecting its height, might be expected to receive the last rays of the setting sun. And finely divided solid or liquid matter has frequently been proved to be capable of so reflecting the sun's last rays. It therefore does not appear probable that diffraction was concerned in producing the principal effects in the twilight phenomena, though some visible influence would undoubtedly be exercised thereby in minute particles widely diffused, and in course of time becoming more homogeneous.

Professor Riccò's Views.

Professor Riccò[†] has, in one of his valuable articles on the twilight phenomena, stated the reasons which to him render difficult the acceptance of Professor Kiessling's theory of the twilight glows as a part of the corona surrounding the sun. He finds, first, that the outer margin of the diffraction corona should be on the horizon when

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[*] The diffraction colours were occasionally visible when the bright glows were but moderate in extent and brilliancy. These diffraction colours were seen as very pale pink and greenish-white arcs before sunrise, moving upwards much less rapidly than the bright colorations from which they were quite distinct.

[†] "Riassunto delle osservazioni dei crepuscoli rossi," 'Reale Accademia dei Lincei,' vol. ii., Series 4a, Session of January 3, 1886.

the sun is 26° below the horizon. But in reality the distance of the primary rosy arc, when on the horizon, from the sun was only 9°. Secondly, the rate of descent towards the horizon after sunset was much more rapid at first and slower near the horizon than would be the case if the arc were a part of the corona, which would descend at a constant rate. Thirdly, the change of form and the dimensions of the coloured arcs were much greater than can be accounted for by the coronal theory; for, the greater obliquity of the diffracting stratum could not produce such a change, as may be experimentally verified. The rosy arc exhibited a great variety of shapes. Fourthly, if the rosy arc had been part of a diffraction ring, its colour would have been produced by the superposition of red and violet in two neighbouring orders; and in the spectrum, beyond the maximum of red, there would have been a maximum of violet, but this was not the case. Fifthly, a corona has frequently been distinctly seen by Professor TACCHINI and by himself, and has been followed by only weak or ordinary twilight. In a former article Professor RICCÒ had remarked on the diverging beams as showing that the glow was caused by matter reflecting direct sunlight.

PART IV., SECTION I. (c).*

THE BLUE, GREEN, AND OTHERWISE COLOURED APPEARANCES OF THE SUN AND MOON IN 1883–84.

By MR. E. DOUGLAS ARCHIBALD.

Simultaneously with, and closely following upon, the eruptions of Krakatoa on August 26th and 27th, 1883, we have, from different parts of the globe, chiefly within the tropical zone, information of the sun appearing blue, green, silvery, yellowish, and coppery; and of the moon occasionally appearing green.

In Section III. (A), p. 312, of this report, the geographical distribution in space and time of these appearances is given in detail.

In the present section we purpose to give a general description of the phenomenon as it was seen in different parts, and briefly to discuss its physical cause and peculiarities.

Before alluding to the coloured appearances of the sun which followed the major eruptions of August 26th and 27th, 1883, we must advert to some which were seen in the neighbourhood of the volcano during its minor eruptions in May of the same

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* In this and subsequent Sections it should be noticed that positions are sometimes given in English notation, viz., degrees and minutes, and sometimes in degrees and decimals—the usual symbols indicate which is employed. Moreover, as on some pages it is impossible to place all the references as foot notes, it is well here to state that the list of such will be found at the end of each Section.—ED.

year. Thus, following on the eruptions of May 20–23, we are told* that at Kroë, in Sumatra, to the west of Krakatoa, the "ashes were so thick that the sun was obscured by them," but in this case no mention is made of the sun being actually coloured. The first of these appearances, which is the one most important in its bearing on the cause of those which succeeded the major eruptions of August, was observed on board the ship *Elisabeth.* (1)† When in sight of Krakatoa, at 9 a.m. on May 20th, a white column of vapour and ashes was seen to elevate itself to a height estimated at 11,000 metres, or nearly 7 miles, by measurements effected (apparently by the aid of instruments) on board.

"After this followed a rain of a very fine grey-yellowish dust which penetrated everything, and which continued to fall until the night between the 21st and 22nd of May. On the morning of the 21st the light was that which prevails during an eclipse of the sun; the sky presented the aspect of a large dome of very thin opal glass, to the vault of which the sun seemed suspended as a pale blue globe. A fall of dust was still observed at a distance of 345 English miles from Krakatoa" (the ship was travelling to Singapore).‡

Again, on May 20th, the *Actæa,* in the neighbourhood of Krakatoa, 6° 50′ S., 101° 2′ E., reports "a peculiar light green colour was observed in the sky to E.S.E., while from E. to E.N.E. there was a dark blue cloud which reached from the horizon to the zenith. About 2 p.m. the day was quite dark, and a very fine dust began to fall, which covered the ship, and only ceased about 9 a.m. on the 21st. The sun looked like dull silver. At noon on the 21st, in 8° 15′ S., 102° 28′ E., the sky remained of a dusty hue. The sky did not assume a natural appearance until the 23rd. (2)

Besides these direct observations of a coloured sun in May, we have the collateral observations on board the *Belfast* (f), from May 24th to July 16th, in 11° 38′ S., 31° 44′ W., to 8° 52′ N., 85° 52′ E., of "a prolonged zodiacal light and other optical phenomena." Then, on July 16th and 17th, the *Belfast* (f) observes "a blue moon after sunset through light haze."

The preceding observations have been quoted mainly to show the relation of the few cases of coloured appearances of the sun and moon after the minor eruptions of Krakatoa in May and June, to these eruptions, and their analogy to the extensive series of coloured suns in particular, which were observed after the major eruptions of August 26th and 27th.

Here again we have a few observations near the volcano, in which the occurrence of a green sun is mentioned, viz., on August 27th, at Batavia,§ the sun was observed to be green after emerging from the cloud or smoke of the eruption;

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[*] VERBEEK'S 'Krakatau,' p. 15.

[†] For numbered and lettered references in this Section, see p. 218.

[‡] This passage is a free translation of one in VERBEEK'S 'Krakatau,' p. 16.

[§] 'Batavia Dagblad.' VERBEEK'S 'Krakatau,' part ii., Notes.

and on the same day, and for several days after, it was observed to be green by the Hon. F. C. P. Vereker, at Labuan Island.*

In the adjacent districts of Sumatra and Java, the sun was probably too obscured during the greater part of the time to be seen at all, and the inhabitants generally were too much absorbed in contemplating the other more striking effects of the eruption to notice the colour of the sun; but the sky was noticed from Serang † to be the colour of lead, and from Teloek Betoeng † to be the colour of copper in the direction of Krakatoa. Here we have the first quotation of the colours of two metals, afterwards employed in more than one description of the appearance of the sun from the Pacific Ocean and other parts.

As the geographical distribution of the coloured suns in the tropics is described in detail in Section III. (A), p. 312, we shall not here follow their appearances in regular succession, but state generally that the results of this investigation prove them to have proceeded at first coincidently with, but within narrower limits than, the other optical phenomena after August 27th, in their double revolution round the globe, and within a zone bounded finally by the north and south tropics.

Beyond these limits the blue or green appearance does not seem to have been witnessed, except sporadically, and in many cases only temporarily, and sometimes merely subjectively by contrast with some adjacent red colour of the sky.

In the continuous series the last clear account of a green sun, from a ship near the equator, is that of the *Olbers*, in 9° S., 35° W. on September 28th, 1883; but subsequent to this we have a notice of a pea-green sun at Bangalore,‡ and again, of a green sun in Ceylon on November 9th, 1883.§

Also Professor Michie Smith, of Madras, seems, after his attention was drawn to it, to have noticed a green moon on May 14th, 1884; but this is alluded to as if it were merely an occurrence which he had hitherto overlooked, and which occasionally appears in those latitudes in connection with excessive humidity.

That in the extra-tropics the coloured sun was by no means generally seen, even temporarily, may be gathered from the following remarks:—

At Wooster, Ohio, U.S.A., Professor O. N. Stoddard || says:—"In no case has the sun during the day, or at setting, appeared green."

M. P. J. Thirion,§ of Nice, says:—"The blue sun has not been observed in our high latitudes; but we have seen the green moon."

Professor Michie Smith ¶ says:—"The green sun was not seen further north than

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* 'Nature,' vol. xxix. (1883), p. 153.

† Verbeek's 'Krakatau,' p. 59, &c.

‡ 'Times of Ceylon,' October 6, 1883.

§ 'Les Illuminations Crépusculaires,' April, 1884. Reprint p. 19.

|| 'Nature,' vol. xxix. (1884), p. 356.

¶ 'Nature,' vol. xxx. (1884), p. 347.

Ongole, except at Vizagapatam, Ragamundey, and Simla; and the dates of observations at these stations are not preserved. It was observed at Bombay, but was so inconspicuous that it escaped notice at the Observatory."

In the extra-tropics the coloured sun was seen, noticeably by the following:—

Duration.	Place.	Observer.	Date.
—	Fétoules, Isère *	F. Perrin	December 24, 1883.
Temporary	Kalmar, Sweden †	?	January 14, 1884.
At sunset	Cracow ‡	Dr. Karlinski	January 24, 1884.
Temporary	Kersal § (near Manchester)	E. J. Bles	February 26, 1884.

The moon, likewise, was observed to be green in the higher latitudes by the following:—

Duration.	Place.	Observer.	Date.
At sunset	Madrid ||	F. Gillman	November 30, 1883.
At sunset	Coniston ||	Arthur Severn	December 2, 1883.
—	— ||	James Macaulay	December, 1883.
Temporary	Worcester ||	J. Ll. Bozward	December 14, 1883.
At sunset	Lesina ‡	Bucchich	January, 1884.
3 minutes	Kalmar ||	?	January 14, 1884.
3 minutes	Stockholm ||	?	January 17, 1884.

Though in many of these cases, especially those of the green moon, the colour was evidently subjective in contrast with the adjacent rosy-tinted sky, or to an eye long accustomed to red light, it was expressly stated by some persons, such as J. MACAULAY, SYDNEY HODGES, Dr. TRIPE, and others, to be green when no red was present. In the case of the sun, it was evidently due to the presence of the same haze which produced the twilight glows and extensive colorations in the tropics.

On the occasion of Venus being seen green by Professor STODDARD,¶ on December 28th, 1883, and January 13th, 1884, he says that the light of the planet was struggling through some invisible medium which arrested the other colours; and in other cases the presence of the haze is frequently referred to.

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* 'L'Astronomie,' 3rd Année, p. 67.

† 'Les Illuminations Crépusculaires,' P. J. THIRION.

‡ 'Zeitschr. für Met.,' vol. xix. (1884), p. 124.

§ 'Nature,' vol. xxix. (1884), p. 427.

|| 'Nature,' vol. xxix. (1883), p. 179.

¶ 'Nature,' vol. xxix. (1884), p. 356.

It thus appears that while the material in the tropical zone was dense enough to produce a blue or green sun and moon continuously during the first few weeks after the eruption, it was only temporarily able to do so in higher latitudes, and under conditions which tended to produce subjective contrast colours.

Besides the blue and green colours so frequently spoken of, we have accounts of a coppery, a silvery, and even a leaden sun in the tropical zone, and in those parts which were reached by the material soon after the eruption.

One of the first observations of a coppery sun was that made by Professor Dixon at Tokio, on August 30th. (3) This is especially interesting in connection with the exceptional transmission of a narrow stream of the haze towards this region, *viâ* Labuan Island and Fisher Island, since it leads us to conclude that this stream must have been of some considerable density. Similar coppery colours were witnessed only close to the Equator, where the main stream which travelled westwards was most dense. For example, it was seen besides only at

(1) Fanning Island, Sept. 4.
(2) 1° 20′ S., 21° W., on West Coast of Africa (*Corona*), Aug. 31.
(3) Guayaquil, 2° S., 80° W., Sept. 1.

In the case of one ship, the *Frieda Grampp* (a), the sun was described as for days together looking like a leaden plate. Such colours, however, were only exceptionally observed, and the sun was generally described as being silvery, blue, or green.

In order to see whether there was any relation traceable between these different colours and their distribution with regard to locality for the first ten days succeeding the eruption, we have placed them in three groups below :—

The Sun was observed—

Date.	Blue.	Green.	Silvery.
Aug. 27..	Kokkulai (4), Ceylon.	Batavia (h). Labuan, Banguey Island } (8).	
,, 28..	Kokkulai.	—	
,, 29..	Kokkulai.		
,, 30..	Kokkulai.	—	*Ida*, (a) 1°·3 N., 108°·4 E.
,, 31..	Kokkulai.	—	*Albert Reimann* (a), 2°·3 S., 4°·7 E. Maranham (c), 2° 30′ S., 44° W. (pale sun), and 2° S., 5° E. (a).
Sept. 1..	Kokkulai. Cape Coast Castle (5). Ship 10° 40′ N., 26° 30′ W.	—	Guayaquil (b). Maranham. *Queen of Cambria* (f), 9° S., 28° W.
,, 2..	Bogotà (9), 4° 43′ N., 74° 12′ W. Maracaibo, 11° N., 72° W. Kokkulai. Paramaribo (6), 6° N., 55° W. Trinidad (a), 10° 30′ N., 61° 20′ W. Medellin (a), 6° 2′ N., 75° 49′ W. Ecuador (a), 3° S., 76° 30′ W. Cape Coast Castle. San Christobal (a), 7° 30′ N., 72° 23′ W. Carupano, 10° 36′ N., 63° W.	Cartagena (a), 10° 22′ N., 75° 32′ W. Panama (7), 8° 59′ N., 79° 32′ W.	Varinas (Venezuela), 8°·6 N., 70° W. (bluish-green 3 p.m. to 5 p.m.). Guayaquil. Maranham.
,, 3..	Maracaibo. Kokkulai.	Panama (7). Medellin, Columbia.	Guayaquil. Maranham. *Olbers* (pale blue), (f), 7°·2 S., 33° W.
,, 4..	Kokkulai.	*Jennie Walker* (d), 8° 20′ N., 155° 28′ W.	
,, 5..	Maracaibo (a). *Zealandia*, 5° N., ? 170° W.	Colombo (10). Honolulu (g).	Maranham. *Superb*, 13° 17′ S., 149° W., and for three days thenceforward to 5° S., 148° W. Tapiteuea, 1° 10′ S., 174° 50′ E.
,, 6..	Strong Island (silver blue), (11), 5° N., 163° 6′ E.	—	*Superb*. *Papa* (a), 8°·1 N., 161°·4 W. (pale as through blue glass). Maranham.
,, 6..	*Zealandia*, 5° N., ? 170 W.		

Thenceforward we hear little more of a "silvery" sun, and the colour appears to have been mainly green. From the above lists it appears that the "blue" sun was chiefly seen at great distances from Java, especially if Kokkulai be omitted as giving positive evidence of its having been seen in the Indian area, the word *nil* for blue and green being the same in Singhalese.* The "green" sun was visible at first only in the Indian Ocean, but afterwards more generally than either of the other colours, and finally the "silvery" sun, when at a high altitude, appears to have been almost entirely confined to a narrow zone near the Equator, and more especially on its southern side. If to this we add the cases in which the sun appeared coppery, dim, and sensibly obscured, we find that they were all † close to the Equator in each hemisphere.

In several cases the sun was not visible when near the horizon. Thus the *Papa*, (a) in 0° 1′ S., 163° 7′ W., reports that the sun on September 9th was hidden in the yellowish veil up to 7° above the horizon; and in 1° 5′ S. and 165° W., the captain of the same ship says that the sun was still veiled with a yellow stratum. In other parts, where it was reported to be green or blue at high altitudes, it was several times spoken of as being dim and giving little light until it had reached an altitude of 10° or more. Further from the Equator, or from the latitude of Krakatoa, the green colour seems to have been visible only when the sun was at a low altitude.

Thus, in Ceylon, at Colombo, on September 9th, the sun was observed to be green when about 10° above the horizon. (12) Also, on September 10th, the *Belfast*, in 18° N., 86° E., reports the sun as blue like the moon, at 4 p.m., changing to green at sunset. (f)

On September 10th, at Madras, the sun was observed to rise of a bright blue colour, and the phenomenon lasted from 6 to 10 a.m. (13)

On the 9th, from the *Pelican*, 10° 4′ N., 64° 13′ E., the sun was noticed to be green in the morning, (14) and also throughout Southern India and Ceylon, chiefly in the mornings and evenings. (15)

Mr. LADD, while passing through the Red Sea early in September, 1883, noticed that the sun, after rising and before setting, and the moon before setting, were observed to be green at an altitude of 20° to 25° above the horizon; and he noticed a point important in its relation to the other phenomena, viz., that on the first occasion "the green moon was covered with thin cirro-stratus, over which the after-glow was cast." (16)

At Madras, on September 12th, it was noticed that the moon, when near the horizon, became a pale green, and bright stars near the horizon showed the same tint. (17)

Similar accounts are given elsewhere.

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* 'Ceylon Observer,' September 15, 1883.

† With the exception of the coppery sun in Japan.

Thus, on September 4th, in the Pacific, the *Jennie Walker* observed the sun green at setting. (a)

At Fanning Island, on the same date, the sun was copper coloured, and on September 17th the *Superb*, in 12° N. 146° W., reports the sun when rising to have been like a green ball. The *Scotia* 12° N. 51° E., observes "the sun green on rising" on Sept. 9th.

At Buenos Ayres the green colour seems to have been noticed up to 20° or 30° above the horizon. (e)

All this leads us to inquire more closely into the question whether the particular colour observed was not in part a function of the altitude of the sun above the horizon.

The following circumstances appear to support this notion :—

At San Christobal, on September 2nd, it was seen to be "silvery at 3 p.m. ; then it became bright blue, and lastly sky blue. At 5 p.m. everything looked blue." (a)

At Cape Coast Castle, on the 1st or 2nd of that month, the sun was described as being blue in the morning. It seems that it, on rising, resembled the moon, and that the clouds which passed over it, from their greater rarity or their density, gave it different apparent shades of rose colour, pink, and so on. After the passage of the clouds, its appearance through the haze was white, like the moon. In fact, an Englishman is said to have taken it for the moon. (5)

At Barbadoes it was observed to be "variously coloured during the day."

The Rev. W. R. Manley, writing (18) from Ongole, says :—

"On September 14th we had the curious phenomenon of a greenish colour in the light of the sun. . . . About 4 o'clock an indistinct bluish tinge appeared in the light. This gradually passed into a greenish colour, and this in turn became tinged with yellow as the sun approached the horizon. As the sun sank, bands of smoky haze drifted across its disc. After the sun was down, bright yellow, orange, and red appeared in the west, a very deep red remaining for more than an hour after sunset. At night, the moon, just past the first quarter, was seen surrounded by a pale greenish halo, about 30° in breadth."

Another similar and important observation (19) was made in Ceylon by a Government officer while travelling from Mannâr to Trincomalee, and is dated Puleadierakam, September 12th. "The sun for the last three days rises in a splendid green when visible, *i.e.*, about 10° above the horizon. As he advances he assumes a beautiful blue, and as he comes further on looks a brilliant blue, resembling burning sulphur. When about 45° it is not possible to look at him with the naked eye; but even when at the zenith the light is blue, varying from a pale blue to a light blue later on, somewhat similar to moonlight, even at midday. Then, as he declines, the sun assumes the same changes, but *vice versâ*. The moon, now visible in the afternoons, looks also tinged with blue after sunset, and as she declines assumes a very fiery colour 30° from the zenith."

We have quoted the foregoing observations *in extenso* since they evidently agree in showing that the colour changed according to altitude, being blue or pale near the zenith, and changing thence through a more brilliant blue to green at from 10° to 20° above the horizon.

When the sun was below the horizon the rays from it were often in turn coloured yellow, orange, and finally deep red.

At Medellin we hear of even a violet, as well as a blue and green, colour having been witnessed. Obviously, then, here we have a case of differential selective absorption, the colours, from the zenith downwards, being arranged in spectral order. If we imagine the haze which gave rise to these peculiarities of transmission to be composed of particles capable of stopping the rays at the red end of the spectrum relatively more than those at the violet end, the phenomenon admits of a fairly simple explanation.

Up to the present few experiments appear to have been made to determine the precise tints transmitted by dust of different kinds when exposed to solar light; and to ascertain what proportion of the result is due to diffraction and what to intrinsic absorption. FARADAY'S experiments* on the colour of gold and other metals have reference only to matter of intense opacity; but the matter which gave rise to the present phenomena had little opacity, and therefore there is little or no analogy between the colours transmitted by metals or oxides in a fine state of division and those produced in the present case, probably by some special absorptive property of the dust.

As the particles which, in the present case, produced the transmissive effects, may have been different from those which fell in the neighbourhood of the volcano, it is impossible to infer what their optical properties were; but it is probable that for the most part they were similar to the highly vacuolated vitreous bubble plates described by Messrs. MURRAY and RENARD as forming the major part of the ejecta from Krakatoa and appearing as grey-green pulverulent matter.

Whether such matter possesses special absorptive and transmissive properties or not we are unable to say, nor can it be determined until experiments have been made with specimens of it; but if the mere question of size would tend to determine selective transmission, we might suppose that at first, and where the stream was densest along the Equator, there was a sufficiency of both the larger red-arresting, as well as of the smaller blue-arresting particles, to produce a general absorption, and thus a silvery light; that, further off, where the stream was less dense, at first there were enough of the larger red-arresting particles to cause a blue sun, when the sun was still high in the sky and shining through only a comparatively small thickness of the stratum. As the sun sank towards the horizon, and its rays became more oblique, they would traverse a larger extent of the lower atmosphere containing more particles of vapour and organic dust, which generally

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* 'Phil Trans,' 1857, p. 145.

appear by preference to absorb or scatter the blue rays. When the sun was midway between the zenith and the horizon, the rays at both ends of the spectrum being thus cut off,* the colour would become green; and finally, as the sun approached the horizon, and the absorption of, and diffraction by, the lower atmosphere became the dominant factor, the colour would change, through yellow and orange, to red, as was generally observed.

Even apart from the influence of the lower strata of the atmosphere, the change in the thickness of the stratum itself, traversed by the more oblique rays, would help to produce the same change in the colour of the emergent light.

For on the same assumption that the haze exerted a selective absorption on the red end of the spectrum, and transmitted the violet end more freely, we should have with increased thickness of the stratum traversed by the rays, a tendency to a change in the colour of the emergent rays.

If i i'† denote the intensities, and α α' the co-efficients of transmission of the two dominant rays transmitted through different thicknesses. We have for the thickness θ where the change of colour would occur,

$$i\,\alpha^{\theta} = i'\alpha'^{\theta} \text{ and } \therefore\ \theta = \frac{\log i' - \log i}{\log \alpha - \log \alpha'}$$

In the present case, if we assume the sun to be blue at the zenith and green at an altitude of 30°, we have

$$2 = \frac{\log 480 - \log 168}{\log \alpha - \log \alpha'}$$

And approximately $\alpha = \alpha' \sqrt{3}$.

It is not therefore unreasonable to suppose that the effect of the increased absorption of the blue rays by the lower atmosphere, with increased obliquity of the solar rays, was partly assisted by the corresponding change in the thickness of the haze stratum traversed.

This would accord with the fact that where the haze was most dense near the Equator or the latitude of Krakatoa, and produced a pale or silvery tint when the sun was high (owing to its being composed of particles of all sizes, and therefore transmitting light of all colours), the sun was frequently mentioned as being quite obscured when within a few degrees of the horizon, although otherwise the air was quite clear.‡

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* That the actual absorption was of this character can be gathered from the paper read by Professor MICHIE SMITH before the Royal Society of Edinburgh, July 7, 1884, in which he says:—"When the sun was near the horizon, besides the absorption at the red end, there was also absorption at the violet end, the spectrum ending just beyond the line G."

† Here $i' = 480$ for green light, α' coefficient for green light,
$i = 168$ for blue light; α coefficient for blue light,
and the value of θ at the zenith taken as the unit of thickness. At an angle of 30° the thickness traversed will be approximately doubled $\therefore\ \theta$ is put $= 2$.

‡ *Vide supra*, and various remarks in Section I. (D), on sky haze.

Subsequently, we must suppose that as the stream of material became more attenuated by spreading into higher latitudes, three factors would come into play :—

(1) The horizontal extension of the haze stratum which would tend to render the selective absorption or obstruction ultimately insensible.

(2) The sifting out by gravitation of the grosser, and therefore presumably red-arresting, particles.

(3) The elimination of accompanying water vapour, if any, by evaporation.

The combined action of these factors and the changes due to varying solar altitude appear to afford a reasonable explanation of the diurnal and secular variations observed.

The ultimate attenuation of the stratum would partly account for the fact that the sun was only rarely seen coloured at all in high latitudes, and then only near the horizon, being also assisted in this respect by the time taken by the material to spread into higher latitudes, and the sifting out which must then have taken place of a considerable proportion of the larger red-arresting particles.

We have omitted to consider the possible effects of water, either in the state of vapour, water-dust, or ice-dust, ejected along with the pumice-dust, because :—

(1) There is no reason to suppose that it would act selectively on light in a different manner from aqueous vapour in ordinary circumstance, which generally stops the blue, and transmits the red end of the spectrum.

(2) Even if it acted like the ice in a glacier, we should have, by analogy, to admit the presence of much more vapour than could possibly exist at such an altitude.

On the whole, it appears most probable that the dust stratum, when the sun was shining through it nearly vertically, affected the light by selective absorption chiefly of the rays of longer wave length, that as the sun descended, the light changed in colour, partly through a change in the thickness of the stratum, and partly by the absorption and diffraction through the lower atmosphere, which would tend to act in a contrary manner, and eliminate the rays of shorter wave length. Finally, diffraction through the stratum and the lower dust, and absorption by the aqueous vapour in the lower atmosphere, would completely overpower the selective absorption of the stratum, and allow a free passage only to the longer red waves.

Mr. LOCKYER, F.R.S., (^{c}) writing on this phenomenon when it was first announced, says :—“ The ejecta from the volcano, however high they were cast into the upper air, would in the first instances have had so much coarse-grainedness about them that the light-selecting qualities of the finest among them would have been entirely over-ridden by the coarser ones, which would be competent to stop light of every kind . . . . Let this pall become thin. The sunlight will traverse it in part; there will still be general absorption, the sun will be seen white, but dim. Now let the coarser particles fall from the upper air, leaving behind only those finer ones, the blue and red molecules to which I have previously referred. Neutral tint will now give way to green."

"Let us assume first that the quantity of red molecules was sufficient to override the blue ones. At sunrise the blue molecules from the volcano would be assisted in their absorption by the blue molecules of aqueous vapour always present. The sun would be green when it first became visible. But let the sun get high; the absorption of the aqueous vapour being then reduced in consequence of the smaller thickness of the air as the sun rose, would allow the predominance of the red absorption again to assert itself, and the sun would be blue at noon, though it rose green." The red-arresting molecules, being coarser than the blue, would "be the first to fall from the upper air as dust, so that long after they have sufficiently disappeared to make the appearance of a blue or green sun impossible, there would be enough floating material in the air at as high a point as the convection currents could have carried it, to reflect the sun's light after sunset, and to prolong the twilight in the direct ratio of its height above the earth's surface."

To give a more detailed account than we have hitherto presented of the appearance of the green sun in the tropics, we have thought it advisable to append hereto the following abstract of a paper read before the Royal Society of Edinburgh, on July 7th, 1884, by Professor MICHIE SMITH, of Madras. ([17])

The rarity of the phenomenon of a green or blue sun makes it desirable to record with the greatest accuracy and detail the observations made during its appearance in India in the course of several days of September, 1883.

The notes taken at Madras at the time of the appearance will best illustrate the general features of the phenomena:—

On September 9, the sun, before setting, assumed a peculiar silvery appearance, and its brightness was so much decreased that for about half an hour before sunset it could be observed with the naked eye. This was noticed, I believe, though to a less extent, on the two days preceding, but I did not myself see it on those days.

On September 10, from 5 to 5.30 p.m., the sun could easily be looked at with the naked eye, yet the limbs were sharply defined. At 5.30 the sun entered a low bank of clouds, and did not fully appear again; but a narrow strip seen through a rift in the cloud at 5.43 was coloured a bright pea-green. Round Madras this colour had been seen in the morning, but in Madras itself clouds concealed the sun till it had risen to a considerable altitude.

Of the morning of the 11th I have no record, but in the evening the green colour was brilliant, and was visible for more than half an hour, being preceded, as on the former night, by the silvery-white appearance of the sun's disk. On this evening a large sunspot, about 1′ long, was so conspicuous an object that it attracted the attention of even the most casual observers.

September 12.—At 10.35 a.m. the moon, which was near the horizon, appeared a pale green. Bright stars near the horizon showed the same tint. From 5.15 to 5.30 the clouds to the east were coloured reddish-brown. At 5.55 the sun rose with a yellowish-green colour, but was almost instantly lost in clouds. It reappeared at 6.4, and was then of a bright green colour; this colour rapidly got fainter, but was quite perceptible till 7 o'clock. In the afternoon the phenomena of the previous nights were repeated and, the horizon being free from clouds, the actual sunset was observed. The entry in my notes is: "6.3.—The sun set as a greenish-yellow ball; cumulus, stratus, and nimbus clouds near the horizon, but moon fairly clear; some blue sky, but hazy." The change from green to greenish-yellow was evidently due to the great increase in the strength of the low-sun-band close to the horizon, which left the strip of yellow between that band and the rain-band by far the most prominent feature in the spectrum.

September 13.—In the early morning there was a good deal of distant lightning. The sun rose of a bright, golden-yellow colour; no green was seen. In the afternoon there were slight showers.

September 14.—Before sunrise the clouds were blue and grey, with patches of red clouds of all sorts—cirrus, nimbus, stratus, cumulus, and mares' tails. Two bright flashes of lightning about 5.30 a.m. In the evening there was a slight green tinge, and after sunset the sky was golden-red till 6.50, while Mercury, seen through the red haze, was twinkling strongly.

September 15.—The sun rose golden. In the evening the sunset was very fine: in the west the colour was golden to orange-yellow, in the east in was greenish; red clouds remained till 7.5. There were very brilliant red "*rayons de crépuscule.*"

From September 15 to September 20 the sunrises and sunsets were very fine, with red and gold, for more than half an hour before sunrise and after sunset.

September 21.—Sunset normal.

September 22.—The sun rose as a yellow ball, and showed distinct greenish-yellow afterwards. From ten minutes before till sunset the sun was greenish-yellow, but the sun was much brighter than on the 10th and 11th.

September 23.—The sun rose very green. At 5.37 p.m. the sun appeared from under clouds, very green; strong absorption in the red end of the spectrum to C; low-sun-bands weak. 5.45.—Clouds greyish-purple. There was only one bank of clouds which was near the horizon; above this was a peculiar greyish haze. At 6 the clouds were of a marked purple colour; breaks near the horizon were reddish-brown. During the night there was a great deal of sheet-lightning in the south.

September 24.—The sun rose bright yellow. The spectrum showed complete absorption up to B; the rain-bands α and β were very thick, and the low-sun-bands less marked than usual. There was lightning all night, beginning in the south and working round to the south-east. It consisted chiefly of sheet-lightning, with occasional zig-zag flashes, but no thunder; the stars were fairly clear except near the horizon. Saturn and the moon, when near the horizon, were both very dim.

September 25.—Sunrise golden-green. In the afternoon the shadows cast on white paper were still quite pink, but the sunset was bright yellow.

September 26.—Much the same as yesterday.

September 27.—Before sunrise C, β, α, the rain-band and the dry-air-band were very strong, but the dry-air-band was less than half as dark as the rain-band. The sun rose golden-red. The spectrum showed signs of clearing up; glimpses of A could be obtained. After dark there was very bright lightning in the west.

September 28.—Spectrum still showed great absorption. Lightning at night.

September 29.—Spectrum absorption still very strong. After dark there was a display of luminous clouds specially towards the east. After 11 p.m. there was very heavy rain, with much lightning and some thunder.

September 30.—Sunrise golden. The spectrum *on* the sun showed A clearly, α was very thick.

October 2.—In the morning, from about 7 to 9, there was a thunderstorm, in which the thunder was almost continuous for about an hour and a half, but although the storm was almost vertical, hardly any lightning was visible. . . . The total rainfall for the day was 4·88 inches.

Accounts were collected from trustworthy observers in various parts of India. All describe the brilliant sunsets of the first week of September, and record the appearance of a green sun on several days. It was seen at Muttum in the south of Madras on the 9th, and continued for several days both in the morning and in the evening. The green colour was then lost, but reappeared from the 22nd to the 28th inclusive.

At Bellary the sun was seen "emerald-green" at rising and setting from the 10th to the 14th inclusive. The observations were not carried on longer.

At Coonoor, on the Nilgiris, the abundance of green tints in the sunsets was noted, but the sun itself was described merely as of a "shimmery" appearance.

The Spectrum.—The spectrum of the sun when green was repeatedly observed and photographed with the large zodiacal-light spectroscope, which is furnished with one large prism of dense glass and a very long collimator permitting the use of a wide slit. The main features of the spectrum taken *on* the sun when green were—

1. A very strong general absorption in the red end.

2. A great development of the rain-band and of all other lines that are ascribed to the presence of water-vapour in the atmosphere, more especially of the group C_1 of *a* and of the band at W.L. 504.

The absorption in the red end was of very varying intensity, but when the phenomenon was at its maximum phase it gradually crept up from about B till past C, as the sun sank towards the horizon. On the 12th, when the sun was within a few degrees of the horizon, the absorption was well marked up to W.L. 621, *i.e.*, to beyond *a*, while at the violet end the visible spectrum ended at W.L. 428, or just beyond G.

The lines A and *a* were never visible even *on* the sun when it was green, and even B could be made out with difficulty from half an hour before sunset onwards, and before it vanished it grew intensely prominent, with enormously thick bands on the less refrangible side. The band C_1 on the more refrangible side of C became very broad and black, while the fine line between this and C remained thin and sharp, and C itself thickened out on the less refrangible side. The rain-band was stronger than I have ever before observed it on the plains, and even with the dispersion produced by a single prism at least eight lines could be measured in it, while many more were visible. The low-sun-band was not very conspicuous, but this was partly due to contrast with the very strong rain-band. The line W.L. 568 at the more refrangible side of the low-sun-band was very well marked, and the band itself seemed to consist of a series of equidistant lines.

The apparently much stronger absorption in the red than in the blue end was a very marked feature, which became still more conspicuous when a photograph of the blue end was examined.

Since the passing away of the abnormal conditions I have made careful observations of the sunset spectrum with the same apparatus, and I find that ordinarily A and *a* are clearly visible as well as B, though at times they are strongly marked, and a good deal of shading is observable between them; C_1 is much thinner, and the rain-band is less prominent than the low-sun-band, which, however, does not now have the appearance of a number of fine lines. The nearest approach to the green-sun spectrum was observed recently during a severe thunderstorm, which was accompanied by a fall of about 1½ inch of rain. A very similar, though less intense, spectrum can be observed almost any evening by taking advantage of the passage of a small thin cloud over the sun's disc. If a lens be used in front of the slit of the spectroscope, the absorption due to the cloud will be seen as a band in the middle of the bright spectrum from the unclouded part of the sun, and owing to the strong contrast, the details of the absorption will be well seen, just as in the case of the spectrum of a sunspot.

Meteorological Phenomena.—The electrification of the air was carefully studied during the green sun period, and the results are rather curious. From September 3rd to 6th the potential of the air was positive in the early morning, diminished to zero between 9 and 10 a.m., then became negative, and remained so until the sea-breeze came on in the afternoon, when the charge was positive again, and continued so all night. The amount of electrification varied greatly and rapidly. On the 7th and 9th the potential was positive all day, on the 8th it was negative for a short time. From the 10th to the 12th it varied in the same way as from the 3rd to the 6th, and this state of matters was repeated from the 20th to the 27th; the electrometer readings from the 13th to the 19th having been normal. All the negative readings were got during a hot land wind from the west. Between the 6th and 9th of September a storm of unusual violence swept over the Madras Presidency from the south-west to the north-east, making itself felt in different ways at different places. The rainfall for September was unusually small all over Madras. The average for fifteen stations was 3·24 inches, not quite half the average for this month during previous years.

The barometric curves for Colombo, Madras, Belgaum, Allahabad, and Calcutta (Alipore) have been drawn and found to resemble each other closely. All over India there was a minimum between the 6th and 7th, a maximum about the 18th, another minimum on the 21st, then a rise, and a third minimum on the 27th.

The first essential in any attempt to arrive at an explanation of the cause of the green sun is to ascertain the precise dates at which the phenomenon was first observed in various parts of the world. It is difficult to do this, for persons are apt to make more precise statements than their observations warrant. For instance, the sun certainly set with a peculiar silvery gleam, but no greenness, at Madras on September the 9th, and yet many persons have assured me that they saw it set green there on that evening. The reason evidently was that after their attention had been arrested by the green sunsets of the 10th and 11th they remembered having noticed something peculiar about the sunset on the 9th, and immediately concluded that the sun had been green on that occasion also. In consequence of this tendency of the mind, the evidence for all the dates given has been carefully tested, and has been found in all cases sufficient to justify the opinion that these dates are correct.

It appears that in Ceylon, in the south part of the Madras Presidency, and at Ongole in the north, the sun was first observed to be green on the evening of September 9th, and that over the east of the Presidency, when seen at all, it was first seen green on the morning of the 10th. The green sun was reported at Belgaum on the 8th, but although the observer was trustworthy, he did not make a note of the fact until afterwards, and it is just possible that it may be a mistake.

The captain of the *Cleomene* reports a green sun and moon on the 9th, 10th, and 11th, when his position was from lat. 8° N. to lat. 16° N., and from long. 83° 30′ E. to long. 88° 40′ E. The chief officer of the s.s. *Pelican* saw the moon greenish on the night of the 9th, and the sun green on the morning of the 10th. The steamer was more than 1000 miles away from Madras, in lat. 10° 4′ N. and long. 64° 12′ E., wind south-west.

Amongst the instances in which the sun has been observed of a blue or green colour, we may notice the following :—

The sun was seen blue by Professor PIAZZI SMYTH on entering the Bay of Palermo, on March 10th, 1872, during a sirocco laden with fine dust. (20)

Dr. BUDDE, while travelling in South Algeria, in 1880, says that he was assured by colonists that the sun seen through the fine dust of a Sahara wind had a decidedly blue colour, a fact which supports the view that the green sun in India and the paleness of the sun were due to volcanic dust from Krakatoa. (21)

RICHTOFEN, in his work on China (vol. i., p. 97), notices that the air in Central Asia is filled with dust, and that the sun seen through it appears merely as a dull bluish disc.

Mr. G. F. CHAMBERS, at the meeting of the Royal Astronomical Society January, 1884, stated that the "engineer of some works at Eastbourne, at which large quantities of sea-beach are crushed by steam machinery, had informed him that he had frequently seen the sun appear blue through the fine dust which rises into the air when the operations are in progress. . . . The sun does not usually appear blue every evening when it sets, owing to the dust particles being too large, and because the aqueous vapour and other gases absorb more blue light than is dispersed by the finer particles."*

One of the most remarkable observations of a blue or green sun, and one which possesses a marked interest in its bearing on the connection between these phenomena and the eruption of Krakatoa, is Mr. Whymper's account (22) of what he saw during an eruption of Cotopaxi on July 3rd, 1880.

After detailing how the smoke was seen suddenly to rise from Cotopaxi, 65 miles distant from the party, who were encamped 16,000 feet above the sea on Chimborazo, he says :—

" Several hours elapsed before the ash commenced to intervene between the sun and ourselves, and when it did so we witnessed effects which simply amazed us.

" We saw a green sun, and such a green as we have never, either before or since, seen in the heavens. We saw smears or patches of something like verdigris-green in the sky, and they changed to equally extreme blood-red, or to coarse brick-dust reds, and they in an instant passed to the colour of tarnished copper or shining brass. . . . The ash was extraordinarily fine. . . . I find that the finer particles do not weigh the 1-25000th part of a grain, and the finest atoms are lighter still. By the time we returned to our encampment the grosser particles had fallen below our level, and were settling down into the valley of the Chimbo, the bottom of which was 7,000 feet beneath us, causing it to appear as if filled with thick smoke. The finer ones were still floating in the air like a light fog, and so continued until night closed in." He winds up by saying, " *The changes from one hue to another had obvious connection with the varying densities of the clouds of ash that passed.*"

Opinions regarding the Coloured Suns of 1883.

Mr. A. C. Ranyard expresses himself to the following effect (23) :—

As to the suggestion that the blue suns were due to aqueous vapour, the heavens in such a case would be covered with cloud ; but the blue suns are not described as having been seen through cloud. Many observers expressly state that there was no cloud. . . . The blue colour of the sun is easily explained on physical considerations. In ordinary circumstances there is not enough dust to affect the colour of the sun ; but if the amount were greatly increased, the intensity of the dispersed light would be increased, and the blue colour of the light dispersed from the part of the atmosphere between us and the sun would sensibly affect the colour of the sun.

Mr. J. Norman Lockyer says (24) :—

" Theory had led me to suspect that, with the enormous thickness of air available

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* 'Knowledge,' March 14, 1884.

in India, absorption at the red end of the spectrum by aqueous vapour would be seen as well as the absorption at the blue, which is so common with us. Seeing the sun a vivid green through the steam of the little paddle-boat on Windermere first led me to inquire into the possibility of aqueous vapour following the same law as that which I think we may now accept in the cases of the vapours of metals. As in these experiments with vapours, absorption of the red end alone was seen, as well as absorption at the blue end alone, the assumption that these two absorptions existed in aqueous vapour at once accounted for the green sun."

The same writer says :—

"Aqueous vapour is composed of molecules capable of stopping both blue and red light; other substances also will stop the red. In ordinary circumstances the red molecules of aqueous vapour scarcely ever come into play; but, if they or any substance capable of acting in this way should be supplied, the sun would as often look green as it does now red."

Professor MICHIE SMITH says (25) :—

"That the green sun is entirely due to water vapour I am not prepared to affirm, for, some observations of Dr. SCHUSTER point to an influence produced by suspended matter in the air.

"Why should vapour if present give green tints? To settle this point I made spectroscopic observations, and, though I have not yet reduced them, I find that they indicate a very marked absorption in the red end of the spectrum, extending nearly to B, with a great development of the rain-band near D on the red side, accompanied by a decided deficiency of the band on the green side, called by PIAZZI SMYTH 'the low-sun-band.' Hence we have less red than usual and more green. This is due, in part at least, to the sun's light passing through a more than ordinary dense stratum of aqueous vapour, for we know that the thicker the stratum of vapour the more is the red light absorbed. But this is not all, for we have quite as much vapour without this green colour; but in these cases the sun is, I believe, not seen at all, but we get strips of green sky, which are often seen. The atmosphere, then, I believe, contains at present a large amount of vapour existing actually as vapour, and not condensed into clouds; hence even a great thickness of it is transparent, except to those particular rays which aqueous vapour absorbs.

"The green colour can be seen only at a particular altitude, for only there is the thickness sufficient to produce the necessary absorption. At higher altitudes the peculiar silvery white is exactly what we are to expect."

Mr. HENRY CECIL asks (26) whether the green sun, seen at about the same time in Southern India, Ceylon, and the West Indies, be due solely to the presence of aqueous vapour. Is not the air in these regions normally surcharged through a considerable period of every year with aqueous vapour? And yet this appearance is so unusual as to create alarm! Can, then, so rare a phenomenon be due solely to so general and common a cause? When LOCKYER saw his green sun through the steam on the boat, were there not also, mingling with the vapour, sulphurous fumes from the funnel?

To this the Editor of 'Nature' appends the following:—

"The sun has been seen green through mist on the Simplon."

Some account of experiments and observations bearing on the subject of blue or otherwise coloured suns will be found in the following papers:—

(1.) "On the Colours of the Atmosphere" (by Professor JAMES D. FORBES, F.R.SS. L. and E., Edinburgh, 1839), which includes reference to numerous antecedent papers on the same subject.

(2.) "Note sur un effet de Coloration des Nuages." Par M. J. FOURNET. 1852.

(3.) Two papers by M. FOURNET in the 'Comptes Rendus,' vols. xlvii. and xlviii., 1858 and 1859, on "The Effect of Aqueous Vapour in causing Blue Suns."

In the first of these, Professor FORBES refers to experiments made by him on the peculiar orange colour transmitted by steam during a critical stage of its condensation, and attributes the colours at sunset to the presence of vapour in a partially condensed state. He only incidentally refers to the blue and green suns of 1831, which he agrees with M. ARAGO in considering as the effects of contrast with an intensely red sky.

M. FOURNET found that the presence of water vapour imparted to the atmosphere a bluish or orange colour. The phenomenon is seen when the sun's light passes through a cumulus cloud which increases in thickness from the border to the centre. It appears most favourably when the sun is hidden by one cloud, and the borders of the neighbouring clouds appear golden or orange tinted. Between this orange-tinted region and the sun's disc a bluish region intervenes, and if in this central region the sun itself is seen through the cloud-veil with more or less distinct contour, it appears blue or pale white or orange.[*]

M. FOURNET apparently attributes this blue colour solely to the effect of contrast with the red border.

These observations leave it uncertain whether the phenomenon of a blue sun, as seen by M. FOURNET, was a purely transmission effect or partly one of contrast with the red border; in which latter case the blue space surrounding it might have been partly a real colour, due to diffraction. If the sun was really seen blue itself, both in these cases and in those after the Krakatoa eruption, the colour must have been due to transmission and not to diffraction.

Finally, Dr. KIESSLING, of Hamburg, has made experiments[†] to see in what

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[*] Professor KIESSLING in 'Met. Zeitschrift,' 1884, p. 119.

[†] Described in the 'Met. Zeitschrift,' March, April, 1884; 'Nature,' vol. xxxi. (1885), p. 439; and in his pamphlet entitled 'Die Dämmerungserscheinungen im Jahre 1883.'

circumstances a coloured sun could be produced. He finds water vapour alone, in dustless air, ineffective. Water vapour in ordinary dusty air, and under conditions which gave rise to a foggy condensation, produced transmission tints varying from brownish-red to grey-blue; but he could not, apparently, produce the green tint artificially (probably because the yellow transmissions through the ordinary lower atmosphere were not present in these laboratory experiments).

All this leads to the conclusions which may be summarized as follows :—

SUMMARY OF PART IV., SECTION I. (c).

(1.) That the appearances of blue, green, silvery, and coppery sun, seen mainly in the tropical zone after the eruption of Krakatoa on August 27th, and sporadically after its predecessor in May, 1883, were produced by the action of a haze which proceeded from the neighbourhood of the volcano, and was composed either of dust and vapours mixed, or of dust alone, probably the former at first.

(2.) That the silvery or pale sun was seen where the haze was most dense near the parallel through Krakatoa.

(3.) That the coppery sun was seen either near the Equator, or where a narrow shoot of the stream occurred towards Japan, and near the eruption, as at Teloek Betoeng, from which it may be inferred to have been caused by dense, and perhaps coarse, dust from the eruption, mingled with lower atmospheric absorbing agents.

(4.) That the blue and green suns were seen further from the latitude of Krakatoa and the Equator, where the stratum was more attenuated.

(5.) That where the sun was seen blue near the zenith, it frequently became green or yellow on approaching the horizon, and *vice versâ*, and that these changes of tint were due to changes in the thickness of the medium and of the lower atmosphere traversed.

(6.) That similar appearances have been witnessed on former occasions (*see* Section V., p. 384), in association with accompanying volcanic phenomena, and in regions where the air was, during the time, charged with terrestrial dust.

(7.) That Professor KIESSLING, of Hamburg, has experimentally obtained a blue sun (1) with a cloud of chloride of ammonium, and (2) with aqueous vapour mixed with ordinary dusty air.*

(8.) That while in the tropical zone the coloured suns occurred for the first month after the eruption co-extensively with the other optical effects, the sun and moon were only occasionally and temporarily seen green at a few places in the extra-tropics; and in some of these it is not certain that the appearances were due to anything more than contrast colours.

E. DOUGLAS ARCHIBALD.

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* Professor KIESSLING kindly showed these experiments to the writer when visiting Hamburg in August, 1887.

References in Section I. (c).

(1) 'Tägliche Rundschau,' 1883, Nos. 255 and 256, and a communication to M. Verbeek by M. Herring, at Batavia.

(2) 'Mercantile Record,' June 16, 1883.

(3) 'Nature,' vol. xxix. (1883), p. 196.

(4) Colonel J. Stoddart, Report, MSS., April 10, 1884 (*ante*, p. 116).

(5) 'Gold Coast Times,' September 14, 1883.

(6) 'Nature,' vol. xxix. (1884), p. 252. From a Dutch paper. E. Metzger.

(7) 'Panama Star and Herald,' 'Nature,' vol. xxix. (1883), p. 152. Hyde Clark.

(8) Letter of Hon. Foley C. P. Vereker, of H.M.S. *Magpie*, dated Labuan Island, October 1, 1883.

(9) 'Hansa,' January 2, 1884.

(10) 'Ceylon Observer,' November 9, 1883.

(11) Letter from Miss Cathcart, September 8, 1883.

(12) 'Nature,' vol. xxix. (1883), p. 7.

(13) M. A. T., 'Madras Mail,' 'Nature,' vol. xxviii. (1883), p. 577.

(14) C. Michie Smith, 'Nature,' vol. xxx. (1884), p. 348.

(15) C. Piazzi Smyth, 'Nature,' vol. xxviii. (1883), p. 576.

(16) 'Quarterly Journal Royal Met. Society,' vol. x. (1884) p. 153.

(17) 'Nature,' vol. xxx. (1884), p. 347.

(18) 'Nature,' vol. xxviii. (1883), p. 576.

(19) 'Ceylon Observer,' September 17, 1883.

(20) 'Knowledge,' March 14, 1848.

(21) 'Nature,' vol. xxix. (1883), p. 177.

(22) 'Nature,' vol. xxix. (1883), p. 199.

(23) 'Knowledge,' March 14, 1884.

(24) 'Nature,' vol. xxviii. (1883), p. 575, and 'Times,' December 8.

(25) 'Englishman's Overland Mail,' September 23, 1883.

(26) 'Nature,' vol. xxviii. (1883), p. 612.

(a) 'Met. Zeitschrift,' February, 1884, pp. 49–65.

(b) M. E. Marence, in 'L'Astronomie,' by C. Flammarion.

(c) J. Norman Lockyer, F.R.S., 'Times,' December 8th, 1883.

(d) 'Nature,' vol. xxix. (1884), p. 549.

(e) Beuf, 'Comptes Rendus,' vol. xcviii., pp. 498, 549.

(f) Ship's log, preserved in the Meteorological Office, London.

(g) "The Equatorial Smoke Stream," 'Hawaiian Monthly.' By S. E. Bishop. May, 1884.

(h) 'Ceylon Observer,' November 2, 1883.

PART IV., SECTION I. (D).

THE "SKY-HAZE" AND SOME OF ITS EFFECTS.

By MR. E. DOUGLAS ARCHIBALD.

Nearly all the observers of the twilight glows, coloured suns, corona, &c., agree in attributing them proximately to the physical action of a peculiar and quite abnormal cirri-form haze which appeared concurrently, and at a great altitude, at first in the Indian Ocean, whence it spread round the Equator, and ultimately towards the poles.

It is especially important to notice its earliest appearance, which, like those of the other phenomena, seems to have occurred shortly after the minor eruptions of Krakatoa in May, 1883.

Thus on May 26th, from the log of *Her Majesty*, (b)* lat. 3° 8′ S., long. 90° E., at 9 p.m., we hear of a "thin haze over the sky through which the larger stars shine."

By itself this latter observation might not be thought to refer indubitably to haze similar to that which appeared after August, but when it is compared with the descriptions of the latter, and the "blue moon seen through light haze" on the *Belfast*, on July 16th and 17th, (b) referred to in Section I. (E), we can hardly doubt that it was a similar manifestation.

After this, the next notice we have of the haze was from the ship *Charles Bal*, on August 22nd, after a minor eruption of Krakatoa, in which it reports, in 15° 30′ S., 105° E. (not very far from the volcano):—"In the E. and N.E. there was a strong white haze or silvery glare." (1) The words "silvery glare" are several times used subsequently by other observers.

On August the 27th, the day of the grand eruption, the *Barbarossa*, in 2·°6 S., 62·°9 E., after mentioning the unusual silvery sunset on that day, reports:—"The sky was covered during the night and likewise hazy, although we had no signs of dew." (a)

On the same day we have the observation on board the *Sea Witch*, when ashore on the bar of Sourabaya, Java, of the sun "appearing dim and smoky, while sounds of heavy cannonading were heard, and the barometer was unsteady." (2)

On the same day the *Simla*, 5° 35′ S., 88° E., reports:—"Air very hazy." (b)

On the same day (27th) Dr. MELDRUM (c) says that the sun was obscured at Rodriguez and the Seychelles, the sky at the latter being reported by Mr. ESTRIDGE to be hazy all day, and followed by a gorgeous sunset. At the St. Brandon Rocks "the sky at sunset had a peculiar smoky appearance, which extended nearly to the zenith in an E.S.E. direction." At Diego Garcia, from August 27th to 31st, the sun

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* For numbered and lettered references in this Section, see p. 230.

was obscured during the day; while at sunset a deep purplish-red glow appeared until 7.15 p.m. At Mauritius, on the 27th, the sky was overcast during the day and the sunset was smoky in the west; and on the 28th the sunset was gorgeous. On the 28th the ship *Charlotte*, 7°·3 S., 106·°2 E., reports, "hazy air," (a) and Captain Loyseau of the *Salazic*, lat. 9° 15′ S., long. 93° E., talks of encountering blinding showers of sand, while the sun was reddish and the sky white. (3a)

On August 28th the haze continued at Diego Garcia, Rodriguez, the Seychelles, and Mauritius, and was observed by the *Simla*, 6° 12′ S., 88° 17′ E., "At 2 p.m., sky very hazy, a fine white powder falling in a constant shower like snow. At 8 p.m., sky still very hazy and dust falling." (b)

On August 29th the *Simla*, 6° 26′ S., 87° 52′ E., reports:—"A very large quantity of dust fell in the past night. Very hazy still, and dust falling. At 5 p.m., sun completely obscured 15° above the horizon, owing to haze;" and at 8 p.m., "still dust." (b) On the same day, the *Coppename*, 15° 30′ N., 57° 30′ W., says:—"Clouds appear dry, smoky, and indescribable, at 8 p.m. At 4 p.m., hot looking stratus in N.W.;" (b) and from August 28th to 30th the *Ida*, in 1·°3 N., 108·°4 E., not far from Java, reports:—"Uninterruptedly hazy air." (a) The *British Empire* 2° 37′ S., 79° 52′ E., also remarks:—"A pale yellowish haze accompanying a fall of dust like Portland cement." (4)

On August 30th and 31st, we have the observation at Tokio, Japan, referred to elsewhere, of a "yellowish-grey haze." And on the latter date the observations on board the *Corona*, 1° 20′ S., 21° W., "at 8 a.m. a metallic sort of haze over sky, sun shining through it quite coppery;" and on board the *Olbers*, in 3° 5′ N., 27° W., of "light clouds visible towards sundown" (very similarly worded to the description of the haze subsequently in the extra-tropics).

On September 1st, the *Queen of Cambria*, in 9° S., 28° W., at 8 a.m., notices "a peculiar thin haze in the air, through which the sun is seen with a clearly defined circumference, and almost white in colour; at 8 p.m., stars dimly visible through haze." (b)

On September 2nd, the *Olbers*, 4° 41′ S., 31° 10′ W., again reports:—"The sun obscured at intervals. At 5 p.m., the sun visible through clouds, pale blue." (b)

On the same day we hear of "a long belt of vaporous sky" at Medellin, in connection with the coloured suns and glows in that part of South America, and a peculiar grey sky through which the sun shone faintly was seen by the *Frieda Grampp*, 10°·2 S., 27°·2 W.; the *Rosario*, 3°·7 N.; and the *Argentina*, 12·°1 S., 36°·9 W. (a)

On September 3rd, the *Queen of Cambria*, 3° 6′ S., 27° 4′ W., reports:—"Before sunrise the haze that is still in the air was fiery red, and the sun, when it appeared, was of a dazzling white colour." (b)

On the same day the *Scotia*, 1° 37′ N., 71° E., reports "hazy overhead;" and on

September 6th the same ship, 5° 52′ N., 58° 55′ E., reports "very fine sand deposited in places exposed to the wind." (b)

On September 3rd, the *Euterpe*, 14° S., 7°·9 W., reports :—" During the last few days there is above the cumulus and stratus clouds a uniform grey cloud mass which frequently covers the entire sky." (a) A similar stratum was observed by the *Argentina*, in 8°·2 S., 34°·6 W. (6)

From September 1st to 5th we have the observation, referred to in Section I. (E.), of the "sun being surrounded by a delicate atmospheric film, through which the sun could scarcely shed its light." (7)

On September 4th and 5th a similar appearance was noticed by the *Euterpe* and *Argentina*, and by the *Papa*, in 10° 19′ N., 161° 21′ W., which reports :—" The sky in the morning is covered with a thin white layer. The sun comes through. The air looks yellow and watery." (a)

On September 6th, Eastern time, the same ship, in 8° 1′ N., 161° 4′ W., remarks :— " The entire sky is covered by an even yellowish-red, high layer of cirro-stratus. The sun pierces through, but looks pale, as when seen through a blue glass, with sharply marked edge, nice for observations, well tolerable to the eye, without nimbus or halo. At night the stars were dimly visible." (a)

Thenceforward we have with little intermission, accounts worded in very similar language, of the sky being "covered with a light haze;" (8) "the sun, when green, stands out from a smoky sky," 8° to 16° N., 87° 30′ to 88° 44′ E. (9) Together with the accompanying phenomena of the blue and green suns, it appeared after the first revolution of these round the globe, at higher latitudes than on its first journey. Thus, while on August 27th, at Mullaittivu and Kokkulai, in Ceylon, the sky was "murky, and the rays of the sun obscured to the east," (10) it does not appear to have been generally observed in Ceylon, or to have reached Madras and other places north, such as Ongole, until its return on September 9th.*

At Ongole, on September 10th, 11th, and 12th, "the sun was blue, green, and yellow. After sunset a peculiar haze covered the sky. It was not of sufficient density to be at all visible except where it reflected the direct rays of the sun. Then it had a singular mottled appearance, with a smoky look along the denser portions, suggesting clouds of smoke or dust in the upper atmosphere." (11)

Again, on September 11th, at Pallai, Ceylon, we hear that "the last day or two have proved very hazy, and the sun shines with a bluish tinge. I followed the large spot on the sun this afternoon without even the aid of smoked glass, the sun's

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* From this observation it appears that the northern edge of the dust-stream from Krakatoa, just skirted the northern edge of Ceylon when starting on its first revolution. Krakatoa being in 6° south, would make the semi-width of the stream 14°.

brightness being so dimmed by the dense masses of blue haze in which he eventually disappeared." (12)

A communication from an observer in 10° 48′ N., 78° 52′ E., September 10th, states that "The sun was shining with a subdued light in a distant and hazy, but otherwise cloudless, sky. It could be looked at steadily with the naked eye. The appearance was decidedly as if the ordinary sun was screened off by a thick stratum of vapour which cut off some of the component rays of white light and made it look green." (13)

At Pondicherry, September 12th, "This is the third time the sun has been dimmed. It is as if it were covered with a thin gauze veil of tender Prussian blue." (14)

It also seems to have lasted in these places for some considerable time. Thus, Mr. PARKER, at Hambantota, Ceylon, says, October 11th :—"There is still haziness night and morning. In the morning for about an hour and a half after sunrise, and in the evening for a similar length of time." (15)

The same stratum afterwards spread over extra-tropical regions, and was chiefly observed by Messrs. RUSSELL, PERRY, BOZWARD, and GLYDE, in England, and MM. KRONE, THOLLON, RICCÒ, JANESCH, POCKELS, and LECHER, on the Continent.

The Hon. ROLLO RUSSELL, who observed the phenomenon very closely, thus describes its second appearance near London on November 9th :—"There was a slight haze on the horizon at sunset, having a greenish-white and yellowish-white opalescence at its upper border. About 15 minutes after sunset the sky was pink, and below the pink a shining green and white opalescence, like a luminous mist. The coloured portion of the sky was fan-shaped and resembled a very high thin filmy cirrus. . . . The illuminated portion seemed not to belong to clouds but to glow of itself, like some super-atmospheric film; and yet the idea of an extra atmospheric cause could not be entertained consistently with its later behaviour." (16)

Herr POCKELS, in Brunswick, writing December 31st, states that after the glows of November 27th, 28th, and 29th, "The almost cloudless sky was covered with exceedingly filmy, wavy, and woolly clouds, which could be seen only near the sun." (17)

Mr. GLYDE (Torquay) speaks of it as "a greyish mist, but tinted pink near the sun, and covering the sky all day. It was higher than the most elevated cirrus." (18)

Professor O. N. STODDARD (Wooster, Ohio) says that it is "not an ordinary cirrus-cloud." (19)

Prof. HAZEN, in Washington, speaks of the sun, in an otherwise cloudless sky, "as shining through a dense haze;" a similar haze being seen round the moon. (20)

Rev. S. J. Perry, F.R.S. (Stonyhurst), says that the haze "bore no resemblance to ordinary haze." (21)

M. Thollon observed the same haze at Nice from November, 1883, onwards, and attributed to it the coronæ round the sun and moon, as well as the lack of definition in astronomical observation. (22)

Professor A. Riccò, of Palermo, speaks to the same effect, and describes the haze as being "minutely and irregularly channelled, as if composed of cirro-strati." (23)

M. C. Mouselle, of Auteuil, photographed the vicinity of the sun in 1884, and says:—"These photographs show a corona of diffused light about it, the intensity of which depends in part on the degree of transparency of the very filmy clouds, having a hazy or stratified appearance, and which seemed to be the sole or principal cause of the corona."

The similarity of the foregoing to the remarks of observers within the tropical zone is sufficiently obvious, and may be further corroborated by a perusal of the Table of First Appearances in Section II., p. 263.

Peculiar Features of the Haze.

(1.) There seems to have been a difference in the quality of the haze as it was first seen near the Equator, and more especially in the Indian Ocean, and as it afterwards appeared in higher latitudes.

Thus, in the former regions the haze seems to have been yellow, reddish, smoky, or white, to have covered the entire sky, and to have been visible at midday, and it is only in these regions that it appears to have been thick enough to cut off some of the component colours of the spectrum, and produce blue and green suns at high altitudes. In these regions it was also dense enough to hide the sun entirely when the latter was within a few degrees of the horizon.

On the other hand, in higher latitudes it appears to have been generally thinner, only partially visible and more like a gauzy cirro-stratus.

Thus Professor Stoddard, in Ohio, says:—"It was invisible everywhere except near the sun;" and Mr. N. S. Shaler * speaks to a similar effect.

Mr. Bishop says:—"Even at Honolulu it was always perfectly transparent and invisible except under certain conditions."

The Hon. Rollo Russell says:—"It is visible (except when very dense or in the neighbourhood of the sun) only about the time of sunrise and sunset. During the day not the faintest trace obscures the clear azure, whereas cirrus becomes more distinct with more daylight." (24)

In England, then, the haze was probably too thin to produce coloured suns, but

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* 'Atlantic Monthly,' April, 1884.

thick enough to be seen and to cause a glow by reflection, when the solar rays fell upon it at a small incident angle.

It is scarcely necessary to remark that the thinning off of the haze in the extra-tropics is exactly what might have been expected if it had its source near the Equator, while the march westward, concurrently with the other optical effects, which it cannot be doubted were proximately due to it, leads us back to the Indian Ocean as the source, and August 27th as the date, of its first appearance in any great quantity.

(2.) It had generally a rippled or striated structure, somewhat analogous to cirrus or cirro-stratus.

Several observers testify to this, including Messrs. PERRY, BISHOP, RICCÒ, SHALER, RUSSELL, REBEUR-PASCHWITZ, BOZWARD, KRONE, and G.A.N. ([25]), and it seems to have been noticed from the very first. Thus, in 3°·2 S., 16°·4 W., the s.s. *Carola* notes that "the atmosphere appeared to be full of very small uniformly distributed clouds." ([a])

The Rev. S. E. BISHOP talks of "a wavy ripple" observable in its structure.

Mr. SHALER, in the 'Atlantic Monthly,' remarks that the haze is "stratified;" and Dr. REBEUR-PASCHWITZ, on December 18th, notices "striæ dipping at different angles." ([26])

The Hon. ROLLO RUSSELL, who carefully observed the haze very closely in Surrey, says that it was more analogous to cirro-stratus than cirrus, but to cirro-stratus seen at a distance, for cirro-stratus seen overhead presents features not seen in the cloud-haze. In fact, none of the *usual* characteristics of the highest clouds were apparent in the earlier phenomena of November and December, 1883. The haze usually resembled simply a haze or smoke, in bands of greater and less density, without *fibres* or angles, but later on, some cross striations became visible in the bright part of the sky after sunset, and these closely resembled the striated cirro-stratus. At a distance, *i.e.*, when seen on the horizon, the resemblance to cirro-stratus seems to have existed from the first in the tropics. The total absence of cirrus forms, such as mares' tails, is remarkable.

Again, he observes:—"It showed the sort of stratification in thin streaks, which often appears in cirro-stratus, but its elevation was evidently greater than that common to this cloud." ([24])

This stratification was not constant, and on some days the structure was amorphous.

Messrs. RUSSELL, SHALER, and BOZWARD testify to a motion being observable in the streaks, though they differ widely in their estimates of such motion, the two latter making the streaks move rapidly in a north-east direction, while the former only once or twice observed an apparent and very slow movement eastwards after long watching on several occasions.

According to the Hon. ROLLO RUSSELL, the direction or axes of the streaks generally lay south-west to north-east, both in England and in Italy. Professor Riccò confirms this,* as well as the indications of a motion in the same direction.

(3.) Its presence peculiarly affected astronomical definition.

On this point we have pretty general testimony, including that of Messrs. Saxby (27), F.R.A.S. (28), W. C. Winlock,† Krone, Piazzi Smyth, &c.

Mr. Saxby says :—"An auroral haze of similar appearance to the red sunset haze will often improve the definition of celestial objects, but this haze shows a decidedly opposite tendency; and α Herculis was so blurred as to be scarcely recognisable at altitudes at which any ordinary haze would have transmitted a tolerable result."

It was found, by the party deputed by the Royal Society to photograph the solar corona on the Riffel, under the charge of Mr. C. Ray Woods, that the year 1884 was exceptionally unfavourable for the work, "in consequence of an unusual want of transparency in the higher regions of the atmosphere, this made it impossible for Dr. Huggins to obtain any photographs of the corona that year in England."(29)

Mr. John Ballot, in the Transvaal, noticed on the 7th April, 1884, that "the sky seemed clear and the stars bright, but on using the 6-inch on Jupiter, the planet presented most of the time just a luminous blurr with spurious images flapping on its sides, which seemed to me to be caused by the glow-producing medium." (30)

Dr. Krone noticed that at midnight the haze obscured all stars below the 4th or 5th magnitude (32), and

Mr. Winlock reports :—"Stars of the 3rd or 4th magnitude, which have frequently been seen on a good observing day, it is almost useless to try for now, the phenomenon is evidently not local."

(4.) The peculiar effects witnessed during subsequent lunar eclipses.

There have been since September, 1883, only two total eclipses of the moon, and there was one large (0·88 of moon's diameter) partial one.

Of the first, April 9th, 1884, no record has been found. The second, that of October 4th, 1884, attracted considerable attention from the abnormal obscurity of the moon. The facts are given at large in several papers in the 'Monthly Notices' of the Royal Astronomical Society, but the following extracts sufficiently indicate its exceptional character :—

Total Eclipse of the Moon, October 4th, 1884.

Radcliffe Obs., Oxford.—Mr. E. J. Stone, M.A., F.R.S., says‡ :—"The eclipse was much the darkest that I have ever seen."

Dun Echt.—Mr. J. G. Lohse says :—"During the totality the moon was very faint, and the copper tint, so conspicuous in other eclipses, was seen only occasionally, and then only faintly."

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* In his paper quoted in Sections I. (b) and I. (e).

† "The Long-continued bad Seeing," 'Science,' vol. iv., 1884, pp. 94, 95.

‡ 'Monthly Notices,' vol. xlv., p. 34.

Stonyhurst.—The Rev. S. J. PERRY, F.R.S., says:—"The usual copper tint of the eclipsed moon was not perceived except towards the close of the eclipse, and then it was only very slight."

Bristol.—Mr. W. F. DENNING says:—"The most noteworthy feature in connection with the phenomenon was that the moon at the total phase appeared far less luminous than usual." . . . . "The firmament grew dark as on an ordinary night when the moon is entirely absent."

Bridport.—The Rev. S. J. JOHNSON says:—"At 9 h. 10 min., the whole of the lunar circle began to be seen through the telescope, but without a trace of the ordinary coppery redness—to quote KEPLER, respecting the lunar eclipse of June, 1620—'*sine omni rubedine.*'"

Clapham, London.—Mr. EDMUND J. SPITTA* says:—"During totality the moon was, generally speaking, exceedingly faint—indeed, at times barely visible to the naked eye—and presented none of the coppery colour usual on those occasions."

The only other subsequent lunar eclipse of importance, that of March 30th, 1885, was not visible in this country, but was observed in Tasmania by Mr. A. B. BIGGS.(31) He says that, at the time of maximum eclipse, "All within the shadow was utterly obliterated—lost in the dead slaty tint of the sky. I could not distinguish a single crater after once it was fairly within the shadow. Not the slightest trace of the coppery tint was visible throughout."

This peculiar absence of the coppery tint ordinarily visible, and in circumstances which are described as having been very favourable for observation, "the sky being free from clouds, and the moon in full view during the whole period of the eclipse," seems to favour the notion that the haze not only exerted a general absorption, but, as the appearance of the blue and green suns show, a selective absorption, more especially of the red end of the spectrum.†

(5.) The radiant point of the wisps or streaks of the haze when the glows were at their best, and the structure of the haze when noticeable, lay apparently some distance below the horizon.

This was particularly observed by the Hon. ROLLO RUSSELL.

(6.) Though somewhat analogous to cirrus, the streaks of haze never presented a curled or twisted appearance, but were, apparently, long parallel bands.

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* 'Monthly Notices, Roy. Ast. Soc.,' vol. xlv., p. 154.

† [Since this was in type an article by Professor DUFOUR has appeared in FLAMMARION'S 'l'Astronomie' (January, 1888), in which he strongly supports the theory that the almost complete invisibility of the moon in 1884 was due to Krakatoa dust, and he refers to M. FLAMMARION having expressed the same view. On turning to M. FLAMMARION'S original statement ('l'Astronomie,' 1884, p. 407), it will be found that he refers to the eclipses of April 25, 1642, May 18, 1761, and June 10, 1816, as previous analogous cases. On comparing these and that of 1620, observed by KEPLER, with Part IV., Sec. V., of this volume, it will be found that in each of these four instances there had been an eruption in the previous year—that of 1815 being the great one of Tomboro.—ED.]

This was generally observed, and appears to indicate that the haze was at too great an elevation to be affected by the vertical, or other movements, which accompany cyclonic and anti-cyclonic systems at lower altitudes.

(7.) At sunset the haze began to shine with a red light soon after the cirrus had ceased to shine; about 20 minutes according to the Hon. ROLLO RUSSELL.

(8.) It had a definite lower boundary. (AITKEN.)*

This also was noticed by Mr. BISHOP.†

SECULAR DURATION.

The cloud-haze not being so conspicuous as some of the other phenomena, except near its origin within the tropical belt, has not been so closely observed. At first it was seen generally throughout the tropics in connection with the coloured suns, corona, and twilight glows, and subsequently with the two latter in the temperate zones. In the former region it was distinctly noticeable, apart from the attendant optical phenomena. In the latter, it was noticed at first only near sunrise and sunset in connection with the twilight glows; but subsequently it was noticed more generally in connection with the corona surrounding the sun in the daytime.

The Hon. ROLLO RUSSELL, at Richmond, Surrey, when observing the glows, and writing on January 22nd, 1884, says:—"It has been visible on every clear day for more than two months, and has been quite independent of wind and weather."

The same observer, when in Italy between January 3rd and 4th, says:—"The intensity or thickness of the reflecting stratum was certainly much less than at the end of November." Further on he says:—"In the glows of December, 1883, and January, 1884, the matter concerned seemed to become thinner."

The Rev. S. E. BISHOP, writing from Honolulu in April, 1884, says:—"The haze, with its glows and opalescent corona round the sun, is still being constantly seen." (33)

After this we do not hear much of the haze independently of the other phenomena, though it certainly continued to be seen whenever the conditions were favourable for a twilight glow, while its prolonged presence is attested by various observations—spectroscopic, astronomical, and polariscopic.

Like the corona, it survived in a modified form the more brilliant phases of the twilight glows; and, like it, appears to have become almost imperceptible towards the close of 1885.

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* Second note on remarkable sunsets, 'Proc. Royal Soc. Edin.,' 1883–84.

† 'American Met. Journal,' August, 1886, p. 129.

THE CONNECTION OF THE SKY-HAZE WITH THE ERUPTION OF KRAKATOA.

The remarkable haze which we have just described, and to the peculiar physical properties of which the other optical effects are attributed, both by those who only casually observed them and by those who subjected them to a more prolonged scrutiny and analysis, appears to have been nothing more or less than the smoke (so-called) of the eruption, attenuated into a semi-transparent film.

It appears to have been manifested sporadically after the May eruption, as well as generally after that in August, the observation on *Her Majesty* on May 26th, 1883, in 3° 8′ S., 90° E., at 9 p.m., of "a thin haze over sky through which larger stars shine," being worded very similarly to those which were noted afterwards in such abundance.

In many cases in the Indian Ocean it was reported simultaneously with falls of dust on ships; and in most cases wherever it appeared, especially in the Indian Ocean, it was accompanied by coloured or silvery suns and by glows at twilight.

On the other hand, there are few detailed accounts in which, where glows, &c., appeared, either haze or a lofty cirro-stratus, or a delicate atmospheric semi-transparent film, or a "peculiar," "smoky," and "indescribable" cloud-stratum is not mentioned as a concomitant.

For the first two or three days after the eruption which ended on August 27th, it appeared over the groups of islands in the south-west part of the Indian Ocean, represented by Diego Garcia, the Seychelles, St. Brandon, Rodriguez, and Mauritius, and by the ships *Barbarossa*, *Simla*, *Charlotte*, *Salazic*, *British Empire*, *Scotia*, and *Ida*—the former representing an area embracing 20° of longitude and 20° of latitude, and the latter a different one covering 29° of longitude by 14° of latitude, and between them the larger part of the Indian Ocean. Later on we hear of its being observed, like the other phenomena, not only over widely distant localities along the equatorial belt, but for days together through considerable ranges of latitude by the *Queen of Cambria* and *Olbers* in the Atlantic, and the *Papa* in the Pacific, showing it to have been of fairly uniform extension, as well as of general occurrence.

The remarks on board the *Corona* on August 31st, and *Queen of Cambria* on September 1st, in particular, are clear in showing its appearance in the Atlantic area soon after its general spread over the tropical part of the Indian Ocean, to have been of a precisely similar character to that observed in the latter ocean, and the following observation on the latter ship on September 13th, in 14° N., 26° 42′ W., accentuates this general uniformity as well as peculiarity of appearance:—"I don't know what to call the *stuff* that is seen in the upper regions, thin cirro-stratus or haze; it was like that seen south of the Equator, first early on September 1st and last on September 5th."

That the haze was the proximate cause of all the other optical phenomena is amply testified to, both by the direct statements of observers, some of which we have quoted in the present section, and also by numerous cases in which its presence is indirectly associated with that of several of the other phenomena.

This fact being once established, forms one of the strongest arguments in favour of the dependence of all the optical phenomena, following both the minor and the major eruptions of Krakatoa, upon the finer material ejected during those outbursts. Moreover it is plain from the earlier records, some of which are quoted in Section II., p. 264, that the haze began close to where the thick volumes of smoke, seen near the volcano, ended.

Mr. Ellery, F.R.S., of Melbourne, and one or two other writers, suggest that the haze itself may have been a secondary chemical or physical effect of the eruption; but there does not seem to be any evidence to show that the intrusion of volcanic ejectamenta into the atmosphere would introduce notable chemical changes into its composition, or that these would extend over a wider area than that embraced by the ejectamenta themselves.

Summary of Part IV., Section I. (d).

The preceding paragraphs present an outline of the chief facts in connection with the cloud-haze, and lead to the following conclusions:—

(1.) That soon after the grand eruptions of Krakatoa on August 26th and 27th, a remarkable dimming of the sun took place in the immediate neighbourhood of the volcano, together with haze and falls of dust on ships, which in one case (the *Scotia*, September 8th, in lat. 10° N., long. 53° E., "still a deposit of sand found") extended no less than 52° to the westward, and more than 3,700 English miles from the volcano.

(2.) That this haze was propagated mainly westwards, concurrently with the other optical phenomena, from the neighbourhood of Java. (In Section III. (c.), p. 337, the exact rate of transmission is worked out.)

(3.) That most observers agree in considering it to be the proximate cause of the other optical effects, including the twilight glows, coloured suns, and large corona.

(4.) That it was densest in the Indian Ocean and along the equatorial belt, where it was often thick enough to hide the sun entirely when within a few degrees of the horizon, besides sensibly colouring its rays when at greater altitudes. In the extra-tropics it was much less dense, and was generally visible only at sunrise and sunset; though even there it peculiarly affected astronomical definition in a manner different from ordinary aqueous haze.

(5.) That while, in some of its features, it partook somewhat of the character of a lofty cirrus or cirro-stratus cloud, it yet differed in many respects from an ordinary aqueous cirrus.

(6.) That it appeared to be far above ordinary cirri, and exhibited an absence of the curls and twists by which such clouds are usually characterised, and which are usually attributed to local atmospheric movements at their level. (Its height being that deduced in Section IV., p. 340.)

(7.) That while it was at a height where the temperature is always far below the freezing point of water, no trace of true ice-halos was observed, and that while it produced some effects, such as coloured suns and glows, which might, in certain circumstances, have been caused by aqueous vapour, the general evidence shows that it contained something besides ordinary aqueous vapour, and that it was either entirely fine dust or a mixture of frozen vapour of water or other substances with dust.

(8.) That the spectroscopic evidence referred to in Sections I. (C), p. 199, and I. (E), p. 231, tends to show that the haze was not gas, but a cloud of solid particles, either ice or dust, which at first cut off the red end of the spectrum relatively more than the violet, and subsequently exercised a general absorption, which was more noticeable in the less intense rays at each end, than towards the middle.

(9.) That it appeared on former occasions (1783 and 1831) in association with pale suns and twilight glows, which were at that time ascribed to contemporaneous eruptions.

E. Douglas Archibald.

References in Section I. (D).

(a) All observations referred to thus are taken from Dr. Neumayer's article in the 'Met. Zeitschrift,' February, 1884.

(b) All observations referred to thus are from ships' logs preserved in the London Meteorological Office.

(1) 'Ceylon Observer,' October 12, 1883.
(2) 'American Journal of Meteorology,' vol. i., May, 1884.
(3) 'Proc. Roy. Met. Soc., Mauritius,' May 22, 1884.
(3a) 'Comptes Rendus,' vol. xcvii. (1883), p. 1101.
(4) 'Ceylon Observer,' October 2, 1883.
(5) 'Japan Gazette,' September 21, 1883.
(6) 'Nature,' vol. xxix. (1884), p. 366.
(7) 'L'Astronomie,' Flammarion, February 1, 1884.
(8) 'Honolulu Advertiser.'
(9) 'Indian Daily News,' September, 1883.
(10) Colonel J. Stoddart, MSS. Report, April 10, 1884. (*See* p. 116 et seq.)
(11) 'Nature,' vol. xxviii. (1883), p. 576.
(12) 'Ceylon Observer,' September 15, 1883.
(13) 'Ceylon Observer,' October 25, 1883.
(14) 'Ceylon Observer,' September 21, 1883.
(15) H. Parker. MSS. Letter dated Hambantota, November 18, 1883.
(16) 'Quarterly Journal, Royal Met. Society,' vol. x. (1884), p. 139.
(17) 'Met. Zeitschrift,' March, April, 1884.
(18) 'Standard,' December 26, 1883.
(19) 'Nature,' vol. xxix. (1884), p. 356.
(20) 'American Journal of Science,' vol. xxviii., March, 1884.
(21) MSS., dated Stonyhurst, March 6, 1884.
(22) 'Comptes Rendus,' vol. xcviii., p. 760.
(23) 'Comptes Rendus,' vol. xcviii. (1884), p. 1299.
(24) 'Quarterly Journal Royal Met. Society,' vol. x. (1884), p. 139.
(25) 'Science,' vol. iii. (1884), p. 4.
(26) 'Met. Zeitschrift,' March, April, 1884.
(27) 'Observatory,' vol. vii., p. 19.
(28) 'English Mechanic,' June 20, 1884.
(29) 'Athenæum,' May 9, 1885, p. 602.
(30) 'English Mechanic,' May 29, 1884.
(31) 'Launceston Examiner,' Tasmania, April 1, 1885.
(32) 'Met. Zeitschrift,' July, 1884.
(33) 'Hawaiian Monthly,' May, 1884.

PART IV., SECTION I. (E).

THE LARGE CORONA ROUND THE SUN AND MOON IN 1883–4–5, GENERALLY KNOWN AS "BISHOP'S RING."

By MR. E. DOUGLAS ARCHIBALD.

With the possible exception of some observations on board the *Belfast*, between 16° 31′ S., 31° 40′ W., and 11° 3′ N., and 85° 53′ E., from May 26th to July 17th, 1883, the first indications of this phenomenon were observed immediately after the great eruption of Krakatoa in August, 1883, and it continued visible until the spring of 1886.

After the grand eruption, on the 27th of August, 1883, the first notice we have of the "corona" is that given in the 'Japan Gazette,' September 21st, in which it is stated that shortly after noon on August 30th "the sun seemed to diminish in power, and a uniform yellowish-grey haze, gradually deepening in intensity, spread over the sky, and at two hours before sunset the sun's rays were blended into a faint halo emerging from a globe of light no larger than the full moon."

A similar, though less definite, observation is that of M. MAREUSE, at Guayaquil, who reports* that the sun on September 1st–5th was surrounded by a light atmospheric film of a coppery hue, through which the sun could scarcely shed its light; it appeared like silver set in gold.

The first detailed observation of it was, however, made by Mr. BISHOP at Honolulu, on September 5th, simultaneously with that of the twilight glows and cloud-haze, which first reached that place on this date.

It is important to notice his description of it, since we are thus enabled to establish its identity with the phenomena witnessed in Europe, America, and other regions, more than two months subsequently. He says (1) :—

"Permit me to call special attention to the very peculiar corona or halo extending from 20° to 30° from the sun, which has been visible every day with us, and all day, of whitish haze with pinkish tint, shading off into lilac or purple against the blue. I have seen no notice of this corona observed elsewhere. It is hardly a conspicuous object."

Since this event it has generally been known as "Bishop's Ring," in honour of its first discoverer.

Next we have an observation on September 8th, on board the *Scotia*, in 10° N. and 53° E., of a "partial halo forming at times round the sun."

The *Thessalus*, on September 16th, in 28° 29′ S. and 81° 45′ E., reports "a red haze round the moon all night."

On September 15th, the *Carola*, in 14°·8 N., 20°·8 W., mentions "a halo as

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* 'L'Astronomie,' FLAMMARION.

visible round the moon, having *a deep red outer margin.*" (²) This observation on board the *Carola* is very important in showing that the ring round the sun was not the ordinary ice-crystal refraction halo, in which the red band is innermost, but a true diffraction corona, in which the red occurs on the outside border. This reddish or coppery border was frequently observed without its ring-character being specially noted. Thus, on September 16th, Mr. MAXWELL HALL, in Jamaica, observed "an unusual copper colour in the sky near the sun, which was afterwards very strongly marked."* On September 15th, the *Superb*, in 10° N., 146° W., noticed a "halo" (?) 45° in diameter.

On September 16th, from the *Coppename*, 42° 0′ N., 39° 29′ W., a halo was observed round the moon at 8 p.m., which may or may not have been the same phenomenon. After this, we have some observations within the tropics in October, which point distinctly to the same corona which was afterwards observed more generally.

Thus, on October 2nd, the *Orissa*, in 18° 17′ N., 86° 44′ E., notices a red glare or halo round the sun, from 25° to 30° in diameter. On October 14th, the same ship, in 11° 37′ N., 82° 57′ E., observes, from 8 p.m. to midnight, "a halo or circle round the moon 45° in diameter;" while on October 17th, the *Glencairn*, in 13° 34′ S., 91° 32′ E., notices "a very broad ring round the moon of a dark reddish colour;" and, in addition to these, we have, on October 10th, Mr. H. PARKER's observation in Ceylon of a lunar corona, the sun being normal (*i.e.*, the green tint had gone), but dimmer than usual at sunrise and sunset, and on October 18th, at Oakwood, California, the sun was seen encircled by a white ring on the day immediately preceding the first appearance of the twilight glows in that locality; while on November 1st, the Rev. A. W. HEYDE observed, at Kailong, Lahoul (Himalaya), a white circular sheen round the sun, of from 40° to 80° in diameter.

Thenceforward we have frequent evidence of the appearance of the corona in Europe, America, Asia, and other parts, in association with the glows and other phenomena in November, December, and January, and everywhere of substantially the same physical aspect, size, and order of colours.

Regarding the order of the colours, while there seems to be some degree of divergence as to the precise quality of the tints, especially of the interior part, there is a general consensus of opinion as to the order being blue or white on the inside, and red at the border, or the reverse of that in the ice-crystal halo.

A high authority, Dr. MELDRUM, F.R.S., who was one of its earlier observers in the tropics, spoke of it at the October, 1883, meeting of the Mauritius Meteorological Society, as "a whitish silvery patch surrounded by a brownish fringe, with a radius of from 12° to 24°, according to the position of the sun."

Other observers describe it as follows :—

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* 'Jamaica Weather Report,' November, 1883.

TABLE I.

Date.	Observer.	Locality.	Remarks.
1883.			
(3) Nov. 1	Rev. A. W. Heyde	Kailong, Lahoul, 33° N., 77° E.	White inside and red outside; never seen before.
(4) Nov. 26	Miss Annie Ley	Lutterworth	White, with broad halo of a pale pink colour.
(5) Nov. (end of) and Dec. (beginning).	Capt. De B. Capello	Lisbon	Whitish light, fringed with pale orange-rose; region not circular.
(6) Nov. 27 and Dec. 15	T. W. Backhouse	Sunderland	Pink outside, with bluish centre; never observed previous to Nov. 27, though a constant halo observer for 25 years.
(7) Nov., 1883, to Feb., 1884.	Hon. Rollo Russell	Richmond	Inner part white, outer pale red or lilac.
(7) During the same time	E. D. Archibald	Tunbridge Wells	Inner part milk-white and outer reddish-brown.
(9) Nov. 30	Herr Wulst	Dessau	Silver coloured, with brownish border.
(10) Dec. 1	Dr. von Bezold	Munich	Whitish in centre, with brownish coloured border.
(11) Dec. 12	Professor Divers	Tokio	Silvery glare, bordered by a dusty reddish-brown or purplish ring.
1884.			
(12) Jan. 2	Herr Metzger	Flensburg	A bright blue spot with a reddish border.
(13) Dec. and Jan.	Dr. Galle	Breslau	The periphery was weak, brownish pale red, and inside a white gleam; inner diameter 20°, outer diameter 40°.
(14) Feb. 8	Professor Le Conte	California	Whitish glare of 20° to 25° radius.
(15) From Nov., 1883, to July, 1884.	M. Thollon	Nice	Glowing white, very slightly tinted with red outside and blue inside.
(16) May 19, 1884	Prof. Riccò	Palermo	Outer rim violet.
(17) Dec., 1883, to May, 1884.	Dr. Assmann	Magdeburg	Outer rim brown-violet.
(18) Sept. 22, 1884	Prof. A. Cornu	Paris	Order of tints of corona from within outwards, blue, neutral grey, brown-yellow, coppery-red, purple-red, dull violet.

The preceding descriptions, which by no means exhaust the entire category, but which we have casually selected to exhibit their general similarity, and the universal character of the phenomenon, show that the sun was surrounded by a white space bordered by a (circular or elliptical) reddish rim; and though there are considerable differences in the description of the precise tint of both the interior and the border, the substantial identity of the phenomenon in different parts of the world cannot be questioned.

Persons differ much in their estimates of colour, and when one speaks of the interior as blue and another as white, we are inclined to suspect that the colour in the first case may have been partly due to contrast with the border, which would naturally first attract attention, and also be more likely to retain it, than the intensely brilliant inner space. It is probable, however, that in the present case the bluish tint spoken of in some cases (though the majority make it white or silvery), may really have had an objective presence, and that the order from within outwards was more that which was minutely described by Prof. CORNU, viz.: blue, neutral grey, brown-yellow, coppery-red, purple-red, dull violet—analogous to the order of the spectrum colours, only flatter in tone.

The average size of this coronal appendage may approximately be gathered from an examination of the different angular measurements (some evidently rather rough guesses) of its radius or its diameter by different observers.

The following list gives nearly all we have been able to collect, including one or two round the moon :—

TABLE II.

	Angular Diameter of Corona round the Sun.			Date.	Observers.	Locality.
				1883.		
(19)		40° [to 60°]		From September 5, onwards ..	Rev. S. E. Bishop ..	Honolulu.
(19)		40° to 80° (?)		November 1 ..	Rev. A. W. Heyde ..	Lahoul.
(20)		50°		November 25 ..	J. E. Clark	York.
(21)		44°		November 25 ..	Miss Annie Ley ..	Lutterworth.
(22)		40° to 45°		December 5 ..	E. Marchand ..	St. Genis.
				1884.		
(23)		50°		January 13 ..	W. G. Brown ..	Virginia.
(24)		40° to 44°		..	Dr. Kiessling ..	Germany.
	[inner.		outer.]			
(25)	20°		33°	..	Dr. Kremser.. ..	Schneekoppe.*
(25)			40° to 50	January 24 ..	Prof. Divers.. ..	Tokio.
(25)			40° to 50	February 8 ..	Prof. Le Conte ..	California.
(26)	20°		40°	March 24 ..	B. W. S.	Hampstead.
(27)			44° to 46°	April	E. Douglas Archibald (By theodolite)	Tunbridge Wells.
	inner.	max. intensity.	outer.			
(28)	21° 36′	30° 20′	42° 52′	May 19.. ..	Prof. Riccò	Palermo.
	inner.		outer.			
(29)	24°		40° to 44°	May and June .	Dr. Assmann ..	Magdeburg.
(30)			48°	July 23.. ..	D. A. Arcimis ..	Madrid.
	inner.	middle of red.	outer margin.			
(31)	14° to 20°	24° to 28°	36° to 44°	Summer ..	F. A. Forel	Switzerland.
(32)	23°			..	Dr. von Bezold ..	Munich.

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* Inserted here after the means had been taken. In computing the means, the extreme value is the outer diameter, and the average or single value for the inner.

TABLE II.—(*continued.*)

	Angular Diameter of Corona round the Moon.		Date.	Observers.	Locality.
	interior.	exterior.	1883.		
(33)	15°	—	September 15 ..	S. *Carola*	14° 48′ N. 20° 48′ W.
(33a)	—	45°	October 14 ..	S. *Orissa*	11° 37′ N. 82° 57′ E.
			1884.		
(34)	30°		January 4 ..	Prof. Hazen	U.S.
(34)	36°		January 4 ..	Dr. Kremser ..	Schneekoppe.

If we take the averages, excluding the doubtfully large value found by Rev. A. W. HEYDE, at Lahoul, and Dr. KREMSER'S, we find the following values for the corona round the sun :—

Inner diameter.	Outer diameter.
21° 7′	45° 33′

These averages accord very fairly with those of Professors RICCÒ, ASSMANN, and FOREL, which appear to have been the most carefully measured of the entire series.

We shall, therefore, as a probable average, take the inner white portion to be 21°, and the entire ring up to the outer red to be 45° 30′ in diameter. The diameter of the lunar ring appears to have been generally smaller, judging from the few observations, and this seems to be natural in consequence of its inferior brilliancy, which would tend to render the extreme red border invisible. From the observations in the Table, there does not seem to have been, and indeed from such a comparatively limited series of observations it would be difficult to infer that there was, any sensible alteration in the size of the "corona" during the first twelve months of its appearance.

Since the preceding paragraphs were written, a pamphlet entitled 'Beobachtungen über die Dämmerung und seine Beziehungen zum Bishop'schen Sonnenring,' by Dr. ALBERT RIGGENBACH of Basle (1886), has appeared, in which the author gives some later observations of the diameter of the corona (Bishop's Ring), when the sun was at a high altitude, and a further list during 1885 of its dimensions at sunrise and sunset.

From the first list we extract the following :—

Year. Month.	Diameter of Ring.			Observer.	Source.
	Inner.	Middle.	Outer.		
1884—Aug. 7 ..	20°	26° to 34°	48°	Flögel	'Das Wetter,' Bd. i., p. 221.
Aug. 22, 23	14° to 20°	24° to 30°	36° to 44°	Forel	'Archives de Geneve,' xii., p. 175.
1885—Jan. 3–5 ..	22°	—	32° to 34°	Kremser	'Met. Zeits.,' Bd. ii., p. 142.
May 9 ..	30°	—	50°	Busch	'Das Wetter,' Bd. ii., p. 115.
July 3 ..	12°	26°	36° to 40°	Riggenbach, in the Engadine.	
Means	20° 12′	27° 40′	41° 48′		

The means from these observations do not sensibly differ from those derived from our former list, though there appears to be a slight falling off in the size of the inner and outer diameters. The individual observations, however, differ so much *inter se*, that no importance can be attached to this circumstance. The means from the entire series of twelve high-sun observations, from November, 1883, onwards, given by RIGGENBACH, are as follows, with our former ones for comparison :—

Diameter of Corona.	Riggenbach.	Former List.
Inner	20°	21° 7′
Middle of the red	28°	28° 10′ (2 obs.)
Outer	44°	45° 33′

The values will be seen to be very fairly accordant, especially when it is remembered that they were measured for the most part by different observers. The second Table gives the diameters of the corona at sunset from sixty-three observations taken at different dates in 1885, and arranged for different solar zenith distances, in order to exhibit the dilatation of the ring with increasing solar depression. The means are as follows :—

Zenith Distance of Sun's Centre.	Diameter * of		
	Inner bright space.	Brightest part of red.	Outer limit of red.
60° to 78°	12°	26°	32°·8
81°·6 to 88°·9	27°·8	32°·4	46°·6
89°·1 to 92°·3	35°	38°·4	49°·2

* Converted from radius as originally given.

Dr. Riggenbach then gives a list of the angular distances of the brightest portions of the purple sunset glow from the sun, at different zenith distances of the latter, in order to show the close connection of the shape and extent of the glow with those of the corona. The mean of thirteen observations of this portion of the glow, gives it a radius from the sun's centre of 18°·6, or a diameter of 37°·2, the sun's zenith distance varying from 92°·1 to 93°·8.

The brightest part of the purple glow, in fact, commences about the middle or brightest part of the corona when this has reached its greatest dilatation.

A few single observations of the corona and the purple glow are placed together for direct comparison :—

1885.	Solar distance of the brightest part.	
	Corona.	Purple glow.
September 15	21°·5*	21°·2
" 16	18°·6	16°·1
" 17	17°·8	17 ·2
" 23	18°·7	18°·7

The relationship between these two phenomena will be considered further on.

Diurnal and Secular Duration of the large Corona.

The corona round the sun appears to have continued everywhere with little change in its character, and only a gradual decrease in its brilliancy, from the date on which it was first observed up to the spring of 1886, and although not observed (or perhaps noticed) so soon as the twilight glows, it was subsequently seen wherever these occurred, and in proportion as their brilliancy waned it came more and more into popular notice. It is possible, indeed, that near the Equator, where the matter causing the appearances seems to have been densest, the corona may have been somewhat modified, so as to appear merely in the form of a glare (such as was noticed by the brig *Hazard* and other ships, to surround the sun), and without the red border which was generally observed beyond the tropics.

It may also possibly have been this fact which caused the remarkable absence of notice of the corona all over the northern parts of South America and at other equatorial places, when the blue and green appearance of the sun was attracting public attention, and that, as Mr. Bishop remarks concerning the twilight glows, which were more noticeable at Honolulu than at Fanning Island, the corona came

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* Radius of the inner limit of the red.

out in its best colours only where the matter was less dense, and therefore, probably, more homogeneous.

The following remarks regarding its secular duration at different places will show something of the nature of its persistence, and we have further evidence that in most places where it was noticed, either simultaneously with, or shortly subsequent to, the glows, it has continued to be seen whenever the conditions were favourable, such as a clear atmosphere, or a cloud which hid the sun's direct rays.

TABLE III.

Period of Continuance.	Observer or Authority.	Locality.
1883.		
(35) All through September	Brig *Hazard*	Pacific, from New Hanover to Honolulu.
(36) September 5 to December 15, 1883	Rev. S. E. Bishop	All through the Hawaiian Archipelago.
(37) November, 1883, to April 3, 1884	T. W. Backhouse	Sunderland.
(38) November 11 to 21	Dr. Neumayer	Switzerland.
(39) November, onwards	Maxwell Hall	Jamaica.
(40) Several weeks previous to December 24	F. Perrin	Mont Fétoules. (The guides said had been seen.)
(41) December to February, 1884	Hon. F. A. Rollo Russell	Richmond, Surrey.
1884.		
(42) February 20 to March 24	Dr. G. F. Burder	Clifton, Gloucestershire.
(43) April	Rev. S. E. Bishop	Honolulu.* (Seen constantly since September 5, 1883.)
(44) Beginning of March to end of April	Dr. Kiessling	Hamburg.
(45) May 14, and for weeks back	C. L. Prince	Crowborough, Sussex.
(46) June and July	C. L. Wragge	Adelaide.
(47) May 18 to September 5 (intermittently)	J. Gledhill	Halifax, Yorkshire.
(48) July 29 to August 3	W. N. Hartley	Switzerland.
(49) July 22 to August 4	Prof. F. A. Forel	Morges.
(49a) November, 1883, to November, 1884	Rev. A. W. Heyde	Lahoul, Himalaya.

And thence Professor **Forel** carries on the observations almost up to date (October, 1886) in the following list, which he has forwarded to the Committee, and which gives all the dates on which he has seen the corona since the summer of 1884:—

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* Another observer, Mr. C. J. **Lyons**, carries it on to May 29, 1884, at the same place.

Year.	Month.	Dates.
1884	July	*22, 23, 25, 26, 28, 29, 30, 31*
	August	*1, 2, 3, 4, 18, 19, 20, 22, 23, 24, 25*, 27, 30, 31
	September	1, 2, 4, 5, 6, 7, 8, 12, 14, 15, 16, 17, 18
	October	26, 27, 28, 29, 30, 31
	November	3, 4, 8, 18, 19, 20, 23, 24, 27, 30
	December	2, 4, 7, 9, 11, 13, 15, 18
1885	January	4, 5, 8, 12, 13, 27, 29, 31
	February	1, 4, 6, 7, 8, 10, 12, 23, 24, 26, 27
	March	7, 8, 9, 14, 15, 17, 19, 23, 31
	April	1, 7, 8, 14, 15, 22, 24, 27, 28
	May	5, 7, 8, 9, *10*, 16, 17, 18, 19, 21, 23, 24, 25, 28, *29*, 3
	June	5, 7, 14, 15, 19, 21, 23, 25, 28
	July	1, 4, 10, 13, 19, 21, 27
	August	2, 4, 6, 7, 8, *9, 10, 11*, 13, 15, 22
	September	4, 5, 6, 10, *13, 14*, 15, 18, 24
	October	2, 4, 7, 9, 15, 16, 22, 27, 30
	November	1, 2, 3, 27
	December	1, 2, 9, 29
1886	January	30 (?)
	February	*19*
	March	14, 30
	April	2, 10 (?) 29 (?)
	May	*7*
	June	3
	July	..
	August	..[*]

NOTE.—The figures in italics represent observations taken during ascents above 1,000 metres; the rest were taken in Swiss valleys at 400 metres above sea level.

The letter is dated December 4th, 1886, and Professor FOREL makes the following remarks :—

"While up to October, 1885, I have noticed the appearance of the ring on the average ten times per mensem; in November and December, 1885, I have seen it only four times per mensem. In the first months of 1886 I have only nine observations, of which three were doubtful, and two were taken in ascents of mountains.

"Lastly, since July, 1886, I have no longer observed the phenomenon. Moreover, though I have been in conditions favourable for observation, and have resided during July and August, 1886, in the Alps of the Valais, at an elevation of over 6,000 feet, and have sometimes attained the altitude of 9,000 feet, I have not observed the slightest indication of "Bishop's Ring." My friends, who permanently reside between 9,000 and 12,000 feet above sea-level, have informed me of the complete disappearance of the coloured circle. The sole observations which I have received during the last

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[*] In a recent letter to 'Nature,' vol. xxxv., p. 501, Professor STONE mentions the corona as invisible during the summer months of 1886, but visible again on October 15, since which date it has not been seen.

six months are (1) that of July the 19th, 1886, during the ascent of Mount Pleureur, 3,706 metres (12,159 feet), by MM. Kundig and Ischam, of Geneva; and (2) that of July the 26th, 1886, on the Col d'Herens, 3,460 metres (11,352 feet), by Mr. Colin Campbell, of Dundee."

Professor Forel concludes as follows:—

"Bishop's Ring has appeared continuously in our country from November, 1883, up to October, 1885. From November, 1885, to July, 1886, it has been observed discontinuously. At the end of 1886 it has become no longer visible."

Professor Riccò, of Palermo, has also forwarded a list of observations, which, though it does not embrace so long a period, is interesting, as showing that the phenomenon was a universal one, and that the gaps in Professor Forel's series were chiefly due to local conditions, such as unfavourable weather, &c. Thus, the ring was observed on the following dates:—

Year.	Month.	Dates.
1885	April	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 17, 20, 26, 27, 29
	May	1, 2, 3, 5, 6, 7, 12, 13, 26, 27
	June	2, 3, 5, 6, 11, 12, 20, 21, 22, 26, 27, 28
	July	6, 21

If these dates be compared with those of Professor Forel it will be found that only ten coincide.

Professor Riccò has also furnished a table of the intensity of the phenomena from its commencement, measured by an arbitrary scale of 0—10. On taking monthly averages of these, where there are enough observations, we get the following results:—

Mean Intensity of Corona.

1883.—December, 6·5.

1884.—January, 8·0; February, 8·0; March, 8·4; April, **8·6** (max.); May, 5·1; June, 6·0; July, 6·3; August, 7·5; September, 6·8; October, 7·5; November, 8·4.

1885.—April, 2·9; May, 2·0; June, **1·7** (min.).

In examining the results of this latter table we must remember that the figures are not all intercomparable, owing to the observations having been made in different localities. Thus, up to May, 1884, they were made at Palermo; in June, at different places while travelling from Turin to Modena; from July to the end of 1884, at Castelvetro, south of Modena; and in 1885, again at Palermo.

Taking, then, the first six and the last three months, we find a gradual rise up to a maximum about April, 1884; and since then evidence of a gradual decline down to June, 1885.

This agrees with other casual evidence in making the maximum of the corona in Europe in the spring of 1884, and about three or four months after the maximum of the twilight glows in the same latitudes. Taking all the facts together regarding secular duration, we find that while the twilight glows ceased to attract attention after February, 1884, the corona survived them with remarkable persistence, and that even up to the spring of 1886, or nearly three years from the time at which it first appeared, it still remained a conspicuous phenomenon.

Its diurnal duration in favourable circumstances seems to have been continuous. Thus, Mr. Bishop speaks of it as being "visible every day and all day," (1) and Mr. T. R. Clapham, of Lancaster, remarks that the corona can be seen any day at mid-day when the sky is clear.

Dr. Meldrum (50) notices that the corona is visible "during the greater part of the day;" and others, such as Professor Le Conte (California), M. Thollon, C. L. Prince, T. W. Backhouse, Dr. Assmann (Magdeburg), Professor F. A. Forel (Morges), C. L. Wragge (Adelaide), and the writer, show by their statements that this was the case all over the world. It was best seen when the lower air was free from dust, as, for instance, after rain, and especially when a dark cloud hid the sun and allowed the red rim to be seen round its border. In such circumstances, as Professor Forel substantially remarked, the lower strata of the atmosphere are in a shadow, and, therefore, the white light, which they usually disperse, no longer obliterates the delicate tints of the corona. (51)

One point deserves to be noticed in connection with the secular duration of the corona, viz., that while in November there was apparently a great decline in the brilliancy of the twilight glows at Honolulu, Mr. Bishop observed that the corona continued unaltered. (52) The same fact was observed during the temporary abatements of the glow phenomena in Europe, showing evidently that the physical cause which produced the corona was independent of certain circumstances which regulated the development of the glows at sunrise and sunset. Since the glows have disappeared, the survival of the corona lends additional support and importance to this conclusion.

The general constancy of the corona under various meteorological conditions, both secular and diurnal, accords with the evidence afforded elsewhere of the elevation of the stratum in which it was generated, far above ordinary atmospheric disturbances, though probably not above upper aërial currents of a continuous and general character.

Peculiar Features of the Corona.

It remains for us to notice certain peculiar features which were exhibited by the large corona after it first became visible in Europe, in November, 1883; and also to point out those in which it appears to differ from all ordinary phenomena of a similar nature.

(1.) It was noticed that while the corona, during midday, and when the sun was at a high altitude, was nearly circular, as the latter declined towards the horizon the corona lengthened out, and the sun, instead of occupying the centre of the ring, became excentric to it, towards its lower boundary. This was noticed specially by W. G. BROWN, of Virginia; (53) Prof. A. RICCÒ, of Palermo; (16) Dr. KIESSLING; (54) T. W. BACKHOUSE, of Sunderland; Prof. CORNU, and Dr. MELDRUM. (55) Dr. KIESSLING explains this excentricity as follows:—

"At sunset the sun has constantly become excentric near the lower border of the central area [a diffraction field], so that when the sun has been at about 10° altitude a strikingly bright glowing blue spot has appeared about 23° to 22° above the horizon from which, when the sun has sunk lower, the first purple glow has been suddenly developed. These observations clearly show that the problematic purple glow is simply the upper portion of a very excentric diffraction image, such as can be experimentally formed by allowing the edge of the cloud molecules to act on a vertical plate of glass, the size of which molecules rapidly increase from above downwards."

This, however, does not tally with the fact noticed, amongst others by M. CORNU, that the lower part of the diffraction ring widens out as the sun approaches the horizon; whereas, if the above cause were alone in operation it should become narrower and more curved at its lower edge.

Prof. CORNU says (56):—

"The concentric reddish corona is the simplest form of the phenomenon. It appears in this geometrical form only when the sun is at great altitudes in the midst of a sky sufficiently clear; but when the sun is lower, the lower arch of the corona widens and becomes more intense. Below this, on the horizon, arises a band of the same colour, which also widens towards the corona as if attracted thereby. This band gradually spreads in every direction, reaches the corona, and resolves itself into a sort of globe. During this metamorphosis the brilliant inner space, of a slightly bluish-white, remains sensibly circular, but, by an easily explained illusion, the sun seems to be excentric towards the lower side."

It seems to us that this latter is the more probable interpretation of the two; though, in favour of the former acting to some extent, we have the *à priori* probability that dust would tend to arrange itself in the order of the sizes of its component particles, increasing from above downwards.

Dr. ZENKER, in an article on the corona,[*] has mathematically exhibited the ellipticity of the corona as the solar altitude decreases as follows:—

Let ϕ = the angular altitude of the sun above the horizon.

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[*] 'Met. Zeitsch.' (1885), vol. ii., p. 400.

2ρ = the vertical angle of the cone made by joining the exterior rim of the corona to the eye.

a, b, the major and minor axes of the section made by this cone on the dust stratum when the sun is not in the zenith.

Then we have

$$\frac{a}{b} = \frac{\cos \rho}{\sqrt{\sin (\phi + \rho) \sin (\phi - \rho)}} .$$

When the sun is at the zenith, $\phi = 90°$ and $a = b$, and the ring is circular.

When the sun is on the horizon, $\phi = \rho$ and $\frac{a}{b} = \infty$, and the curve becomes a parabola. Finally, when ϕ is $< \rho$, $\frac{a}{b}$ becomes negative, and the curve is an hyperbola.

Dr. A. RIGGENBACH, in his pamphlet already referred to, thus explains the widening of the corona as the sun approaches the horizon * :—

"The widening of Bishop's Ring, which begins about half an hour before sunset, and reaches its maximum soon after sunset, arises solely from the reddening of the sun's light by its absorption in consequence of its longer path through the lower atmospheric strata; and is to be conceived as a transmutation of the diffraction image from a white source of illumination into that from a monochromatic red. At the same distance from the sun where, shortly before the disappearance of the ring, the maximum brightness of the red lies, the purple glow first makes its appearance."

From this and the preceding extracts, it is evident that considerable diversity of opinion prevails as to the cause or causes of this particular phase of the phenomenon.

(2.) Another feature of the corona was its variation when seen at different altitudes above the surface of the earth. This has been noticed both by Mr. T. W. BACKHOUSE, of Sunderland, and by Professor FOREL, of Morges. Both observers concur in finding the corona more brilliant when seen through a clearer atmosphere, such as exists at lofty altitudes. The former describes the phenomenon as being far more striking on the summit of the Görner Grat, 10,289 feet above sea level, than down below, and even at a height of 4000 feet it was more definite than at sea level. (57) Professor FOREL says (58):—"I verified the influence of altitude on the corona. Starting from the hospice of the Grimsel, 1870 metres (6135 feet), where the red circle was well defined, I saw its intensity gradually diminish as I descended into the valley of Hasli; at Innertkirchet, 625 metres (2051 feet), the red was imperceptible, but it reappeared on ascending to Rosenlaui; and at the Grand Schiedeck, 1960 metres (6431 feet), the corona was in its full lustre. I never saw it more brilliant than when on the high *névés* of the Fée, 3000 metres (9843 feet), Rhône, 2800 metres (9187

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* 'Beobachtungen über die Dämmerung,' &c., p. 16.

feet) or Lower Aar, 2550 metres (8366 feet), glaciers." And again:—"I saw the corona in the Alps of the Valais and Berne from August 18th to 26th. As soon as I reached 1000 metres (3281 feet) the phenomenon reappeared; at 1500 metres (4921 feet) it was very distinct; at 2000 metres (6562 feet) to 3000 metres (9843 feet) its brilliancy was extraordinary."

These observations are important as showing that the phenomenon essentially belonged to the upper aërial regions, and are easily explained by the fact that the dustier and the smokier air of the lower strata would tend to overpower by their diffused light and perhaps also to absorb the delicate mono-chromatic tints of the corona more than would the purer and more translucent air of the upper regions.

Although, as we have before remarked, the corona was observed from places only slightly elevated above sea level to be substantially independent of weather changes, it was noticed to be more brilliant with certain phases of weather than others, especially after rain, and when the lower strata were less hazy and smoky than usual. In fact, the smoke of large cities, such as London and Berlin, seemed to render it almost invisible. Such variation, however, was plainly local and confined to the lower atmosphere alone.

Certain secular changes of colour, however, independently of those due to the state of the lower atmosphere, appear to have been noticed by a few persons, amongst whom was Professor G. H. STONE, of Colorado, who, in a paper presented to the Colorado Meteorological Association,* notices that the corona, or "sun-glow," as he terms it, was orange in November and December, 1883, pink or reddish-brown in April, 1884, and then diminished in intensity, becoming slightly orange again in the autumn of the same year. Since then it had become dull reddish-brown.

"It was least intense during July and August of 1884 and 1885. It was most intense during November and December, 1883 and 1884."

The same writer notices likewise certain variations of intensity with particular phases of weather, the maximum of brilliancy occurring during cold weather, and especially before a cold storm, and he subsequently endeavours to trace a causal connection between the two; but as the sun-glow, or corona, was in all probability formed in the same haze which caused the glows, and which evidently, both from its height and behaviour, had very little connection with the ordinary currents and movements of the lower atmosphere, this was mainly owing to the lower air being clearer at such times.

In support of this, Mr. HELM CLAYTON, writing to the same journal in June, 1886, says:—"Observations have been taken for several months on the visibility of the ring and of distant mountains at Blue Hill Observatory, and there has seemed to be a close parallelism between the two in New England. The ring has always appeared brightest when the mountains were clearest, and has disappeared when the mountains

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* 'American Meteorological Journal,' vol. ii., No. 11, March, 1886.

disappeared from view." Professor STONE's last communication, which again combats this view, is appended :—

DISAPPEARANCE OF BISHOP'S RING IN COLORADO.*

"The reddish ring about the sun first distinctly appeared here (at the base of Pike's Peak) on November 22nd, 1883. For several days before that date, a faint discoloration of the region about the sun had attracted my attention. This gradually grew more intense, and, on the day mentioned, became unmistakable. The subsequent history of Bishop's Ring as seen at this place is, in brief, as follows :—

"The colour was most intense during the winter of 1883–84, and diminished in brightness from that time until its disappearance. At first it was visible almost all the time. Later, it appeared only at the time of cold storms, which were accompanied by great vertical movement of the air, or when, for any reason, the clouds reached to a great height. It was, on the average, brighter during the winters than in the summers; also, it was brighter when the sun was near the horizon. Many times in cold weather there has been not a trace of the ring, although the air was so clear that peaks a hundred miles distant were distinctly visible from the heights behind this city. At other times the ring has been very bright when the air was so hazy that the mountains only 10 miles away were hardly visible. During the later months of 1885 it was invisible most of the time, but suddenly flamed out in wonderful intensity at the time of the great norther of January 9th–11th, 1886. Then for about two months it frequently appeared in the morning, or towards evening. During the warm months of 1886 it was not seen. On October 15th it appeared distinctly. About a week later it appeared very faintly a few times, and since then I have not been able to see a trace of it. My observations have been made at elevations of from 6000 to about 13,000 feet, and there was but little apparent difference in intensity at the different elevations. It is well known that the atmosphere here is, in general, very dry and transparent.

"The diffraction-ring was often more coppery, almost rosy, in tint at the time of the northers, and in the thickening haze in the upper air preparatory to hailstorms. The great intensity of the colour at such times, and its peculiar tint, and that, too, irrespective of the amount of haze in the lower atmosphere, makes it probable that the ring was in part due to diffraction on ice-particles. If so, the ice-particles may themselves have been due to precipitation on dust-particles. The fact that no diffraction-ring has been seen around the sun during the past winter is not conclusive, for we have had no great northers, the season being unusually mild. But the disappearance of Bishop's Ring for so long a time makes it certain that, even if there can be a circum-solar glow due to diffraction on ice-particles, yet the proper conditions for such a ring are realised only rarely, except when there is a great amount of volcanic dust in the air."

"G. H. STONE."

"Colorado College, Colorado Springs."

Regarding the almost continuous change of tint of the corona from orange to dull reddish-brown as time went on, it appears that this was most probably due not to any special change in the matter which caused it, such as the introduction of ice coating the dust, as is suggested by Professor STONE, but was simply a result of the corresponding decline in intensity, allowing the less brilliant colours to be more absorbed by the lower air. This explanation agrees with what has already been said regarding the effect of change of altitude on the brilliancy of the phenomenon. There seems, therefore, to be no general evidence to show that any sensible variation

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* 'Nature,' vol. xxxv. (1887), p. 581.

took place in the appearance of the phenomenon, as it would have presented itself from day to day to an observer on a lofty mountain, other than a gradual decline of brilliancy as time proceeded. This fact appears to be of considerable importance in relation to the proximate physical cause of the phenomenon.

(3.) Another peculiarity of this corona is, that while ordinary coronæ of small dimensions are frequently observed during the temporary passage of a cloud across the sun's disc, this large and nearly constant corona does not seem to have been witnessed previous to its appearance in 1883, even by those ordinarily accustomed to scan the heavens.

Thus Mr. BACKHOUSE says:—"It has been habitual for me to scan the neighbourhood of the sun for halos during 25 years, and I never observed it previously to the date mentioned. . . . . It is, therefore, very difficult for me to believe that the corona was visible in this country much, if at all, before last November." (59)

MM. THOLLON and PERROTIN (60) speak to the same effect, in that, while they had previously always found the sky clear, they "have, since November, 1883, found the sun surrounded by a circular zone of glowing white, very slightly tinted with red outside and white inside."

The Rev. W. CLEMENT LEY, a world-renowned sky observer, says that the corona was "unlike anything he ever saw before." And numerous other observers testify to the same effect.

Professor VON BEZOLD says that he noticed a white glare round the sun in former years, but had never before observed the brown ring. (61)

Obviously, then, we have here a phenomenon which for size, brilliancy, universality, and protracted duration, appears to be unique in the annals of Optical Meteorology.

THE CONNECTION BETWEEN THE CORONA, OR BISHOP'S RING, AND THE UNUSUAL TWILIGHT GLOWS.

From the simultaneous appearance of these two phenomena in 1883, it has been supposed that they were not only due to a common cause, but were merely different manifestations of the same physical effects.

The gradual blending of the former into the latter, and the similarity of the colour of the outside of the ring, which would be the last to survive after sunset, to that of the final tint of glow when near the horizon, tend to support this notion, which has been upheld chiefly by Dr. RIGGENBACH* and Professor KIESSLING.†

The former refers to the connection as follows:—

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* 'Beobachtungen über die Dämmerung.'

† 'Die Dämmerungserscheinungen im Jahre 1883.'

"The purple light begins to brighten up at that part of the sky where, at the sudden disappearance of the sun, one would perceive the brightest part of Bishop's Ring. After two or three minutes, when the extent of its area has become measureable, it grows similar to the extension of the ring in size and width. Then the purple light increases both in the direction of the sun and in the reverse, but more especially in the latter, beyond the boundary of the ring, and attains its maximum area simultaneously with its maximum brilliancy, when the solar depression lies between 3½° and 4½°. At this time the purple glow occupies the whole of the western sky, from about 6° up to the zenith, and its seat is in the atmosphere from 5 to 13 kilometres (16,400 to 42,700 feet). After some time, when the extent of surface covered by the glow has ceased to expand, the purple quickly withdraws towards the sun, and it disappears, on an average, when the whole atmosphere below 6·4 to 9·5 kilometres (21,000 to 31,170 feet), visible from the place of observation, lies in the shadow. The lower part of the purple phenomenon remains after the maximum of light at nearly the same distance from the sun, and it is visibly nearer the sun than the inner part of the ring. At the brightening of the purple glow still higher portions of the atmosphere (perhaps up to 22 kilometres = 72,180 feet) may emit red rays, in which case the exterior part of the purple glow shrinks before extinction to about an amount nearly equivalent to the interior part of the ring."

Prof. KIESSLING has closely investigated the cause of the various phases included under, and exhibited during the prevalence of, the unusual twilight phenomena of 1883-4, and appears to attribute them all, with the exception of the second after-glow, to diffraction through the elevated cloud-haze, and to consider them to be continuous modifications of the physical conditions which gave rise to Bishop's Ring throughout the day.

He includes the ring as part of the twilight phenomenon, and after explaining the excentricity of the sun with respect to its circumference as it approaches the horizon, to be due to diffraction through layers of particles increasing in size from above downwards, attributes the sudden appearance of the purple glow near the centre of the deformed ring to accumulated diffraction, principally of the red rays, through a part of the cloud stratum which receives the sun's rays horizontally for some considerable portion of its length. According to this explanation, we should have to regard Bishop's Ring as representing symmetrical diffraction through the haze which, when the sun sinks below the horizon, gradually merges into a special form of mono-chromatic diffraction by horizontal rays, and still conclude that conditions which might favour the development of the one phase would not necessarily promote the brilliancy of the other; for, the ring, during the day, would represent the effect of the general diffraction through the entire layer, and would reach its maximum brilliancy when this layer reached its highest *general* homogeneity; whereas the glow proceeding from some definite stratum or boundary of the haze might be subject to certain influences[*] which would affect portions of the haze without altering its general composition.

This *might* account for the non-simultaneous occurrence of the secular maxima of the glows and of the corona, as well as for the fact that on single days, "when the twilight glows were most striking, the ring was not exceptionally conspicuous."[†] At the same time, Professor KIESSLING'S theory leaves out reflection and transmission, which are shown in Section I. (B), p. 198, to account for the main features of the glows, especially of the secondary glow, which was the chief feature of the present series.

IN OPPOSITION TO THE VIEWS OF DRS. RIGGENBACH AND KIESSLING.

Professor RICCÒ,[‡] in a careful *résumé* of his observations of the twilight glows and attendant phenomena from December 3rd, 1883, to April 30th, 1884, concludes that the corona and the primary glow are not only separate phenomena, but are not physically related to each other in the manner indicated by Professor KIESSLING.

His reasons may be summarised as follows :—

(1.) From calculations, taking account of refraction, the mean solar depression at the disappearance of the primary glow on the horizon is 9°·5. On the other hand, the distance of the sun from the region of maximum brightness of the red in the corona is 15°·2, and from that of its exterior boundary 26°·4.

(2.) The appearance of diverging crepuscular rays in the primary glow which the author, following other authorities, attributes to interception of the horizontal rays near the earth's surface by distant mountains, shows the primary glow to be due to direct and not to diffracted light.

(3.) The unequal rate of descent of the edge of the primary glow, which on the average is about 1° in $1\frac{1}{2}$ minutes, and the constant rate of descent of the corona, which follows the sun and descends from 0°·17 to 0°·18 per minute, or 1° in about $5\frac{1}{2}$ minutes.[§]

The equation expressing the variation in the height of the rosy twilight is thus expressed by Professor RICCÒ :—

$$V = 37^{\circ}{\cdot}13 \sin {}^{2}K,$$

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[*] Such as those mentioned in Section IV.

[†] Dr. ASSMANN, 'Met. Zeits.,' vol. i. (1884), p. 196.

[‡] 'Riassunto delle osservazioni dei crepuscoli rossi,' Nota i., ii., iii., 1884–5–6, R. Accademia dei Lincei.

[§] Professor RICCÒ does not say what happens to the corona when the sun goes below the horizon. Most observers say that it fades away—whether subjectively or objectively does not seem quite clear.

where V represents the variation per minute, and K the angular height of the edge of the glow above the horizon.

The radius of the corona is found to vary according to a totally different empirical law expressed by the following equation :—

$$R = 26^\circ - 7^\circ{\cdot}16 \sin \tfrac{2}{3} K.$$

In fact the radius of the corona becomes 26° when the sun is on the horizon, as observed by Riggenbach[*] and others.

(4.) The fact, already noticed, that in April, 1884, when the twilight glows were weak and rare, the corona was at its maximum intensity. Moreover, in January, 1885, when the extraordinary glows had for some time ceased, the corona was observed several times very distinctly.

(5.) Professor Riccò observed a special development of the corona, viz., the brown arc surrounding the sun at sunset from December, 1883, to December, 1884, fifteen times strongly marked (intensity $\underset{>}{\equiv} 8$), followed by weaker twilight glows (intensity $\underset{>}{\equiv} 5$); and Professor Tacchini similarly observed, from January to December, 1884, the brown arc strongly marked and followed by weak displays of the twilight glows. Also the former observed the arc four times, and the latter fourteen times, not followed by twilight glows.

(6.) The descending corona is not able to change, except in a slight degree, its form and its dimensions through atmospheric refraction. The greater obliquity of the diffracting stratum is not able to produce a change in the form and dimensions of this coloured ring, as may easily be experimentally verified with a glass sprinkled with lycopodium powder, and held with varying obliquity between the eye and a source of illumination.

(7.) If the rosy arc (of the twilight glows) formed part of a diffraction ring, its colour would be produced by the super-position of the red and the violet of two rings of a neighbouring order ; and in its spectrum, besides the maximum in the red, there should be also a maximum in the violet, which is not the case.

Professor Riccò, in fine, considers the extraordinary glows to have been *superposed* on Bishop's Ring, but not *produced* either by it, or by diffracted rays, but, as far as the primary is concerned, by the direct solar rays.

Professor Riccò's arguments appear to demolish in great measure Professor Kiessling's view that the primary sunset glow is entirely due to diffraction, and until they are effectively met by the latter, we incline to the view already put forward in Section I. (b), p. 199, in which some further considerations are urged against the purely diffraction hypothesis, and in favour of that which accounts for both the primary and the secondary glows at sunrise and sunset, mainly by reflection of rays already tinted by diffraction through, and absorption by, the same stratum,

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[*] 'Beobachtungen über die Dämmerung.'

and the dust and vapour normally existing in the lower atmosphere. Regarding the disappearance of the ring at sunset, Dr. ASSMANN says:—"The ring was always fainter a little before sunset, and soon after was quite invisible." And again, Prof. CORNU[*] says:—"After sunset the corona has the appearance of a slight haze, and gradually vanishes; the colours blend with those of the setting sun, but generally in the higher regions, and they remind us of the finest roseate hues of the last winter's evenings."

GENERAL OPINIONS REGARDING THE CORONA.

We shall here give a brief *résumé* of some general remarks by a few of the leading observers regarding the character and causes of Bishop's Ring.

Dr. ASSMANN,[†] referring to certain phenomena witnessed during an ascent of the Brocken, says:—"These rings and wreaths certainly gave one a strong impression of the existence of a thickly distributed dusty material sweeping along in close contiguity to the earth. That no form of aqueous vapour could have caused this ring is evident from its optical peculiarities, as also from the instructive combination which occurred on January 13th between 12 and 2 p.m. in the form of a portion of a regular solar halo and of a luminous mock-sun near the brownish-violet haze circle, the mock-sun being at least 2° beyond the circle. The connection of these coloured rings with the abnormal twilight phenomena is very probable."

Professor H. KRONE, in an article in the 'Met. Zeitschrift,'[‡] says of the red region surrounding the twilight glows:—"This red region seems to be identical with the ring seen by FALL. I cannot, however, agree with FALL in placing this ring in the category of solar and lunar halos, that is to say among the interference phenomena which are wont to accompany light when transmitted through ice-needles. . . . . This ring is no other than the red region of the less refracted rays, yellow, reddish-yellow, and red, caused through *refraction* of the sun's rays by the atmosphere, especially with high atmospheric pressure. . . ."

Professor VON BEZOLD, in a letter to Professor KIESSLING[§] (October 24th, 1884), says:—

"I have observed for years the bright glow during a high sun, and the bright spot above it when it is below the horizon. I was, therefore, so far inclined to doubt the argument which CLAUSIUS brings forward in his treatise on the colour of the atmosphere, that no water globules, but only water vesicles, were present in it, because, in the first case, the sun would always be surrounded by a large pale sun image of nearly 60°, which is not the fact. I often said to myself, 'Such an image is

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[*] 'Comptes Rendus,' vol. xcix., p. 490.

[†] 'Met. Zeitschrift,' vol. i. (1884), p. 197.

[‡] *Ibid.*, vol. i. (1884), p. 277. 'Bericht über die vulkanische Ausbrüche des Jahres 1883,' von Dr. NEUMAYER.

[§] 'Das Wetter,' 1884, p. 178.

actually present, although its extension does not quite correspond with the conditions of the theory; and I have for years inferred a connection between this glow and the purple light, but since no one took any interest in my twilight observations I let the fact drop, and confined myself to occasional observation.

"On the other hand, in spite of the close attention I bestowed on this bright shine, I have never before observed the brown ring, which surprised me for the first time on December 1st, 1883, the same day on which the unusual twilight glows appeared, and which I have now very often, particularly during this autumn, seen with wonderful development. I have also for the first time observed the reddish colours in the interstices between the clouds [in daytime] during this last winter."

Professor LE CONTE, of California, (62) regards the ring as a diffraction phenomenon, but mixed with an imperfectly developed ice-halo, and hence accounts for the feebleness and blending of the tints.

M. THOLLON (63) says that the phenomenon was visible at Nice from November, 1883, to July, 1884, and that, as he was quite certain he had never observed similar phenomena in former years, he concluded that some remarkable change had occurred in the atmosphere from that date in that locality. He says also that the corona is evidently produced by diffraction through some light powder.

Professor FOREL, (65) from an examination of European records only, concluded that an immense dust-cloud existed suspended in the air over Central Europe.

Prof. CORNU* remarks that, in favourable circumstances, the order of the colours in Bishop's Ring is as follows:—

"Proceeding from the centre outwardly, clear azure blue, neutral grey, brown-yellow, orange-yellow, coppery-red, purple-red, and dull violet, which is analogous to the succession of the colours of the first ring of diffraction coronæ presented by thin clouds. We can often make a direct comparison. These vivid hues are not always produced when the spaces open on the coronæ, as a second condition is necessary, viz., that the hazy reds seen shall be in the shade, otherwise the colours are flooded with white light. This condition is evident when we follow the sun's beams across those spaces, since it is only beyond the reach of these rays that these red tints of fiery lustre are observed. These observations seem to indicate that the phenomenon has its seat far above the cumulus (perhaps above the cirrus), and that it acquires its most extraordinary intensity when viewed from spots where there is no terrestrial haze."

Professor PIAZZI SMYTH says (66):—"That such appearances [those noticed by him on September 3rd, 1884, and by Mr. BACKHOUSE, in the Alps,] were produced by solid particles in a cold state, and not by any new gas introduced into the atmosphere, seems to be borne out by three sets of rather extensive solar spectroscopings which I have lately carried out; for while there does not seem to be a single new line amongst the thousands of old ones, as far as I have yet examined the observations,

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* 'Comptes Rendus,' vol. xcix., p. 490.

there is only too abundant evidence of a continued dulling of the light of the sun's continuous spectrum along its range.

"This effect is, of course, more conspicuous in the faint regions at each end than in the bright middle, and appears to be testified to undeniably by the following differential observations, viz., that with a prismatic apparatus wherewith I could see lines in the bright regions, say, of B, C, and D, rather better than I could with somewhat similar but darker prisms in 1877, I could not see Brewster's line Y, and its companion groups in the very faint ultra-red, so well as I did then; and could not see the further-away line X at all, though in 1877 it was not only clear enough, but far fainter lines on each side of it were visible, and micrometrically measurable. Neither in 1884 have I been able, with the same eye and instrument, to see anything at the violet end of the spectrum of the grand banded lines H and K, though they formed a daily subject of observation in 1877. In 1856, I remarkably appreciated that an ascent to 11,000 feet on the Peak of Teneriffe enabled H and K to be seen with peculiar distinctness and fine resolution of much of their haze at lower levels into sharp lines," &c.

These observations are evidently important, not only in their negative bearing on the cause of the corona, but in their positive bearing on the general absorption exercised by the haze.

Prof. KIESSLING has studied the diffraction phenomena in the laboratory and also in the operations of nature, and we shall here quote the results of some of his experiments and remarks, as they have a very important bearing on the cause of the corona as well as on that of the entire range of optical effects which began in August, 1883.

His experiments * (a detailed account of which is appended to this section, p. 258) lead to the following conclusions:—

(1.) That when the particles are of the same size, a condition which is not ordinarily fulfilled in smoke and cloud, either dust, or dust and vapour together, transmit with solar light coloured coronæ; but that when the particles are of different sizes the diffraction image is colourless.

(2.) That when the air is filtered from dust, and vapour is introduced into the diffraction chamber, and the temperature is lowered, no trace of diffraction rings is visible with transmitted light.

(3.) On introducing ordinary (and therefore dusty) air into the chamber, and lowering the temperature and pressure, a ring with a bluish interior and a broad red border is obtained, very similar to the corona of 1883. The finest effects are obtained by starting with a maximum of vapour tension, the colours changing as the temperature and pressure are lowered, showing two marked stages.

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* Partly described in the 'Meteor. Zeitschr.,' vol. i., 1884, and partly in his pamphlet, 'Die Dämmerungserscheinungen im Jahre 1883.' Leipzig, 1885.

In the first, the order is as follows, from the centre outwards :—" Pale lilac, pale bluish-violet, bright blue, bluish-green, emerald-green, yellowish-green, greenish-yellow, bright orange, dark orange, pale scarlet-red, pale purple-red."

In the second, when the temperature and pressure are much lower, the order of the colours from the centre is as follows :—" Pale purple-red, stone-green, luminous olive-green, yellowish-green, luminous bronze-yellow, orange."

To obtain a bluish central field with a broad reddish-brown ring, a little smoke must be added to the vapour.

As Prof. KIESSLING considers the entire series of optical effects which began in August, 1883, to be due to diffraction, we cannot here refer to his general views regarding the connection between these and the eruption of Krakatoa ; but may notice, with reference to the corona alone, that, according to him, the phenomenon may have been produced either by diffraction through dust alone, or through a homogeneous cloud formed round the finest dust particles.

The necessary homogeneity in the former case, he thinks, may have arisen from the heavier particles of the dust clouds ejected from the volcano having been sifted out by gravitation, leaving the remainder so nearly of the same size that they were capable, by themselves, of producing the coloured diffraction phenomena. He mentions, also, having produced clearly coloured diffraction rings with finely sifted and pulverised cement.

Regarding the general question as to whether the haze, or whatever produced the corona, was solely dry dust or smoke, or partly or entirely minute ice spiculæ formed, as AITKEN would tell us they generally are, round dust nuclei, the corona alone does not give us a decided answer, since diffraction through such spiculæ might produce a corona of the same angular dimensions as that produced by dust of the same size and shape ; and the fact that the angular diameter of the corona in the present case was almost exactly the same as that of the refraction halo for ice prisms, viz., 45°, might be thought a sufficient reason for the absence of the latter. Dr. ASSMANN'S observation, however, quoted above, of a solar halo appearing on January 13th, 1884, seems to make it plain that if there had been a halo produced in the haze, which was the seat of the ring, it would have been at once detected as a separate phenomenon. If, therefore, the corona was formed by ice prisms surrounding dust nuclei, it seems strange that, while the corona was always visible, there was no trace of a refraction halo in the same stratum, as we should be led to expect.

Besides this negative evidence, there are many other considerations in favour of the notion that the haze which caused all the unusual optical phenomena was composed chiefly of dry dust. Some of these have been already noticed in Section I. (B), p. 195, in which certain peculiarities presented by the glows appear to find their explanation solely on this hypothesis.

We may here add a few more :—

(1.) The fact that in cirrus, or cirro-stratus ice-haze, in which alone refraction halos are seen, coronæ are seldom if ever observed. On the other hand, in the lower clouds, where water occurs in minute spherules (water dust), coronæ are frequently observed. KAEMTZ[*] says :—" Coronæ occur in the middle of cumulus, halos in cirrus." Now, it can scarcely be doubted that any water vapour which occurred in the cloud haze would, at an elevation of from 60,000 to 120,000 feet or more, be entirely frozen into ice-spiculæ resembling those in the cirrus. We should, therefore, by all analogy and experience, have expected halos rather than coronæ to prevail in this elevated stratum. Instead of this, however, we find no traces of halos in the haze, but a persistent brilliant and immense corona such as has never before been witnessed. In the absence, therefore, of any special evidence to show that ice-spiculæ could be formed and continue at such an elevation (which on meteorological and physical grounds is very improbable[†]), and of so minute a size as to produce so large a corona, or that they should give rise to a corona in preference to a halo, contrary to what occurs in the cirrus and cirro-stratus, the constant occurrence of this large corona for two or three years must alone be considered as evidence in favour of the haze being composed chiefly of dust.

(2.) The remarks of Mr. AITKEN, in his paper referred to in Section IV., p. 346, as to the sifting rather than absorbing influence of the haze, which he proved by means of the polariscope.

(3.) The peculiar effect of the haze on astronomical definition, and the effects witnessed during lunar eclipses (Section I. (D), p. 225) ; and

(4.) The general evidence from Mr. VERBEEK's report, that the ejecta from Krakatoa during its eruption on August 26th and 27th, were mainly fine and *dry* pumiceous dust, the rain of mud occurring only locally and temporarily, more than 20 hours after the principal explosions had commenced.[‡]

SUMMARY OF PART IV., SECTION I. (E).

Taking all the facts regarding the corona, or Bishop's Ring, together, we arrive at the following conclusions :—

(1) That the date on which it was first distinctly seen was September 5th, 1883, by Mr. BISHOP at Honolulu, after which it appeared at most places where the other optical effects were witnessed ;

(2) That its principal colours were bluish-white in the centre, shading off into a reddish-brown border, the diameter of the inner space being about 21°, and the entire ring, to the external boundary of the red, about 45° 30′. Round the moon the

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[*] 'Meteorology,' translated by WALKER, p. 431.

[†] See "General Analysis," Section VII.

[‡] This point is further considered in Section VII.

only colour distinguishable was a pale-reddish circular boundary, the apparent diameter of which was somewhat smaller than that round the sun :

(3) That when it was visible it appeared all day from sunrise to sunset under favourable conditions :

(4) That it reached its maximum intensity about the spring of 1884, since which time it gradually declined in brilliancy and visibility, down to June, 1886. Since this latter date it has not been seen even by one of its most careful observers, Professor RICCÒ :

(5) That it was best seen at great altitudes ; and near the earth it was best seen on days when the air was free from ordinary dust or smoke :

(6) That it appeared to be independent of all ordinary atmospheric disturbances :

(7) That it was most probably formed in the haze stratum, which proximately caused the twilight glows and other optical phenomena :

(8) That though a white glare, resembling its inner portion, had been observed in previous years by Professor VON BEZOLD, he had never before seen a corona of the same size and with the marked reddish border :

(9) That it was a diffraction corona produced by the accompanying haze, and that its great size proves this haze to have been composed of exceedingly small particles :

(10) That the order of the colours shows it to have been most probably a diffraction ring of the first order :*

(11) That the occurrence of a corona in so elevated a region, as well as the general absence of accompanying refraction halos, tends to show that the particles through which the diffraction took place were solids, and dust rather than ice :

(12) That while the corona was associated with the twilight glows and coloured suns in being produced by the same elevated haze, it was physically distinct from either, and probably contributed only very slightly to the glows, after the sun sank below the horizon :

(13) That, from Dr. KIESSLING's experiments, it appears that exactly similar phenomena can be produced on a small scale by diffraction of the sun's rays through minute dust, or vapour momentarily condensed in ordinary dusty air.

THE SIZE OF THE PARTICLES WHICH PRODUCED THE LARGE CORONA, OR BISHOP'S RING.

The size of the particles has, by two observers, been estimated as follows :—

		Millimetre.		Inch.
(67) Professor FOREL	at	·003	=	·00011
(68) Herr FLÖGEL	at	·001	=	·00004

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* See Prof. CORNU, p. 252, and Professor RICCÒ, in his paper already quoted.

The writer of the present section, taking the mean value of the inner and outer diameters of the corona to be 21° and 45° 30′, and taking the former to represent the position of the bright violet and the latter that of the red ring, obtains the following results :—

The formula employed is—

$$\mathrm{Sin}\,\frac{D}{2} = N\frac{\lambda}{d},$$

where—

d = the diameter of a dust globule ;

D = the angular diameter of the ring of the particular colour chosen ;

λ = the wave-length of the colour ;

N = a constant whose values for the rings of the first and second orders are 0·7655 and 1·7571 respectively.*

We shall give the values for the first and second orders, though everything points to the probability of the entire corona, as seen, belonging to the first order.

The radius to the middle of the ring is taken to be 15° 10′, the value given by Professor RICCÒ for the position of maximum intensity. Since in diffracted spectra the middle of the spectrum coincides with the position of the rays of maximum intensity, this will give us values more probably correct than either the radius to the inner or to the outer boundary, both of which were less definitely marked.

Diameter of the Particles (supposed Spherical) causing Bishop's Ring.

	1st Order.	2nd Order.
Inner diameter 21°	·00165 mm.	·00379 mm.
Middle ,, 30° 20′	·00162 ,,	·00376 ,,
Outer ,, 45° 30′	·00150 ,,	·00346 ,,
Means	·00159 mm.	·00367 mm.
	= ·00006 in.	= ·00014 in.

It will be noticed that these values are very fairly accordant, the discrepancies showing that, if anything, the internal radius was measured somewhat too small or the outer too large, but the total difference is very little.

If we take the mean of both the values from all three diameters for the first and second orders, we get ·0001 inch, which is the same as that given by Professor FOREL ; but as we take the ring to have been of the first order, we shall adopt as the most probable value ·00006 inch.†

E. DOUGLAS ARCHIBALD.

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* For the values of these constants the writer is indebted to Professor STOKES, P.R.S.

† This is about three times the mean length of a wave of light. Some of the particles, however may have been smaller than the length of a wave of red, and perhaps even of violet, light.

APPENDICES TO CORONA SECTION.

Discussion and Account of Experiments in Connection with Diffraction Coronæ, and Bishop's Ring, by Professor KIESSLING.*

When the sun's rays are passed through a cloud formed of sulphate of ammonia, formed by sulphurous acid and ammonia vapour, an image is formed, which rapidly changes in colour from a dark copper, through violet and crimson, to a brilliant azure blue. In a moist air these changes are more rapid than in dry. Clouds formed of phosphoric acid, sal ammoniac, and gunpowder smoke give the same results. In the case of the sal ammoniac cloud, steam intensifies the blue, and causes it to occur earlier; a steam or aqueous vapour cloud in air gives rise to colours between brownish-red and dark grey-blue. The green colour could not be artificially produced. LAUGIER made an observation on the island of Ouessant [apparently a blue sun] ('Comptes Rendus,' vol. 39) in 1854, which prompted the accurate research into the action of aqueous vapour in causing blue sun, made by FOURNET in 1858 and 1859 ('Comptes Rendus,' vols. 47 and 48), and by LISSAJOUS, March, 1858. FOURNET found that the atmosphere was never pure white when aqueous vapour was present, but was always more or less orange or blue. Cumulus clouds, increasing in thickness from the circumference to the centre, showed successive phases of the phenomenon as the wind wafted them along. In most cases, if the sun was covered or dimmed by clouds, the borders of the neighbouring clouds were gilded, and the clouds themselves coloured orange. Between the orange-coloured zone and the sun's radiating disc is a blue space; and if the sun passes behind a cloud-veil with more or less sharp contours, these become blue or dull white, or orange, according to the density of the obscuring cloud. (See also 'Phil. Mag.,' vol. 58, 1821, p. 234.) [He then refers to the dimmed and coloured suns seen in 1831 and 1883, which, he says, were apparently due to volcanic dust clouds.]

If the diffraction chamber be filled with moist air which has been thoroughly filtered and freed from dust, and the temperature be lowered, then a cloud is formed which is visible only in direct sunlight. It consists of very minute, very scattered, cloud particles, which do not produce the slightest trace of coloured diffraction rings with transmitted light; evidently because there are too few of them in the chamber. A slight cloud is formed in dustless air, which resolves itself into small rain without cloud.

On introducing a little ordinary air into the chamber, a smoky cloud is formed at once, in addition to the large drops of rain. If through this mixture of cloud and rain we look at a screen of tissue paper placed immediately behind the diaphragm of the heliostat, which is about 2 cm. broad, a yellowish-brown halo, with reddish-brown boundaries, is formed, just of the colour and size of the ordinary lunar halo. If a diminution in pressure be made to occur simultaneously with a sudden lowering of temperature, then larger and more distinctly coloured diffraction rings are formed, without the already existing diffraction image being in the slightest degree altered. Hence it follows that in the above-described process of condensation, the first formed cloud-particles are not vesicles but true water droplets; for if, under ordinary atmospheric pressure, the first cloud-formation consisted of vesicles, a rapid decrease of from 80 to 120 mm. of pressure would necessarily cause a rapid expansion of the vesicles and a correspondingly rapid decrease in the diameter of the first diffraction rings formed thereby. But it is not so. At the first moment of decrease of pressure there is a broad central space which becomes a trifle smaller only during rapid colour changes, whereby it forms a group of concentric distinctly coloured rings, so that in the course of one or two seconds, two diffraction figures appear, one over the other, differing greatly in size and colour (the second being the less vivid of the two). With continued decrease of pressure the diameter of the two ring systems gradually diminishes simultaneously. CLAUSIUS has thoroughly discussed this subject in his 'Die Lichterscheinungen der Atmosphäre' (Leipzig, 1850, pp. 392, 396; 'Pogg. Ann.,' vols. 76, 84, and 85); and

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* Abridged and translated from 'Met. Zeitschrift,' vol. (1884), pp. 117 *et seq.*

Burkhart-Jezler has more recently ('Pogg. Ann.,' vol. 145) endowed the vesicular theory with decisive importance. The formation of bright diffraction colours is in complete accordance with Fraunhofer's theory, that they necessitate clouds formed of particles of, as nearly as may be, the same size. This presupposes the presence of a fine dust, which is ordinarily existent in the air of rooms, and in the atmospheric layers nearest the earth, and appears to be most efficient in acting upon light when the air is saturated.

This is most readily effected when the air has passed through water at 30° to 40° C., before being introduced into the diffraction chamber, and when the decreased pressure causing a reduction of temperature is spread over at least a minute. When these conditions prevail, the development of colour is so intense that a sectional figure of the cone of diffraction rays emitted by the bell-glass is formed upon a screen of white tissue paper, placed at a distance of 1 metre . . . the colours of which, in specially favourable circumstances, that is, when the constituent particles of the cloud are as nearly as possible of the same size, rival in intensity those of a solar spectrum of large dispersion viewed objectively. The amplitude of this, depending upon the size of the cloud corpuscles, varies between 10° and 30°. In consequence of the intimate dependence of the intensity of the light upon the uniform structure of the colour-producing clouds, great care is required in the objective representation of intensely bright diffraction images; since only dull colours are formed when the water is too hot or too cold.

The diffraction image undergoes a remarkable change of colour when the pressure is continually diminished. This, however, occurs only in the incipient stage of cloud formation, and generally presents two periods, at the termination of which the colour remains constant; yet the last phases of the first period are so constant under some conditions, that there is no change of colour with a decrease of 10 to 20 mm. in pressure, and consequently of 1° to 2° C.

The rapidity of the succession of colours depends upon the degree of humidity, and upon the rate at which the temperature is lowered, which would be materially influenced by the walls of the relatively small diffraction chamber. The dependence of the colour tone upon these two factors is very close. An accurate determination of it will require further investigation. The colour changes are perceived in the central area, as well as in the surrounding concentric rings. This can be distinctly observed—objectively by means of the image cast upon a transparent screen, or subjectively by direct observation of the sun's light which has passed through the diffraction chamber, or by interposing a transparent screen of tissue paper about 2 cm. in diameter, in front of the heliostat. The observation of the colour development in direct sunlight is attended with difficulty, partly because the eyes suffer from making such observations, but mainly because the images are so transitory, owing to the formation of air-layers of different temperatures which mix together, that the originally coloured concentric rings of the diffraction image are soon lost in the brighter but distinctly coloured reciprocally penetrating cloud-image. On this account I have investigated the colour changes in the last-mentioned ways only. The colours then always appear less bright, and also undergo a modification, but not an important one, in the higher tones of colour, namely, the yellow and the red shades. In the presence of the electric light the development of colour is especially interesting in modifications between blue and violet.

At the very commencement of the depression of temperature there is originated a white, silvery shining, excessively thin, and thoroughly transparent cloud, of which the first, very transitory, colour appears to be a dull violet; the diameter of the central field varies according to the amount of vapour present, between 15° and 60°. Then the following colours rapidly succeed each other in the central area: dull lilac, dull blue-lilac, brilliant clear blue, bluish-green, emerald-green, yellowish-green, greenish-yellow, bright orange, dull orange, dull scarlet, and crimson-red. This closes the first period. Each succeeding colour appears to spread over the preceding one, which then contracts in diameter, so that an image is formed composed of richly coloured concentric rings. This encroachment of colour, however, does not proceed uniformly, but some rings sometimes become so narrow as to be indicated only by a transition tint, so that the succession of colours in the spectrum is apparently interrupted. I have not yet been able to ascertain the cause of this abnormal occurrence, which must stand over for future investigation.

All the colours are mixed, but are suffused with such a peculiar soft glowing light that it is exceedingly difficult to represent them by means of water-colours. The estimation of the colours in the several phases of the development is rendered especially difficult, partly because the colour is rapidly dulled in consequence of the formation of fresh cloud-particles from the continuously wet walls of the diffraction chamber, and partly because a constant change is proceeding in the rings as well as in the central area, owing to the changes of temperature. A stationary condition first supervenes at the end of this period. This is pre-eminently the phase of the colour development, during which the central field is orange, the first ring a bright green, and bluish-green ; and the second, if of moderate breadth, comprises all shades between blue-violet and crimson-red. The whole aperture of the cone issuing from the diffraction appears to be nearly 40°, and in especially favourable circumstances, that is when the cloud is very homogeneous, it amounts to 70°. If we allow sal ammoniac clouds to rise within this cone, then these appear to be green-blue or purple-red, as soon as they catch the rays of light. This phase also is nearly stationary ; dull crimson in the central area, surrounded by a broad green and a narrow blue-violet ring. This phase may often be watched for 15 or 20 seconds without showing any change.

The second period of colour-change in the central area shows a much narrower range of colours, which now always partake of the character of mixed colours overlapping one another. The colours are : crimson-red (with an approximately violet glow), stone-gray (with an approximately green glow), bright olive-green, yellowish-green, bright bronze-yellow, and orange. If the decrease of temperature (as a consequence of diminution of pressure) be continued, the orange becomes more red and bluish in tone, so that there is a sudden renewal of the colour which characterises the beginning of the second period, crimson-red ; then a repetition of the second period sets in, but in gradually fading colours, which become less distinct as the density of the cloud increases.

As aforesaid, the development of colours is closely dependent on the humidity ; so that when there has been a reduction of temperature after the introduction of rapidly succeeding streams of dry, dusty air, and of air supersaturated with moisture by passage through hot water, there is often a parti-coloured mixture, lasting 10 to 15 seconds, glowing with all the colours of the spectrum, and forming a vortex of cloud particles, in which the contrast between purple-red and emerald-green interpenetrating cloud masses is quite sharply defined on opposite sides of the cloud mass. This seems to represent the same condition of things as occurs in the well-known Brazilian twilight phenomenon called "*arrebol*," which has been fully described by BURKHART-JEZLER.

The dependence of the colours upon the specific nature of the medium is particularly well displayed if the upper part of the diffraction chamber be warmed by means of a gas flame. This checks the formation of the large cloud particles in the upper part of the glass. If, now, the temperature be lowered, and the diffraction image be such that the central area has the colour of the final orange of the first period, the upper part will be green at the base and blue at the top, and will allow of the recognition of sharply defined colour-changes of distinctly larger radius.

If this warming be continued so that a space at the top of the chamber at least 10 cm. deep is brought to a temperature of about 50° to 60° C., and there is on the floor of the diffraction chamber (which must be so connected with the air-filter that all differences of pressure brought about by the warming and subsequent cooling may be equalised) a cold and wet sponge ; then a cloud forms itself, which first originates at the boundary between the upper warm and lower cold air, and rapidly spreads from below downwards, while the upper part of the glass gradually becomes clear. This is a condition of things which ALLUARD regularly noticed on the Puy de Dôme, in the winter of 1879–80, and especially in that of 1881–2, where, for example, he noticed 1°·3 C. at Clermont and 8° C. on the Puy de Dôme. If the sun's rays be allowed to enter the diffraction chamber parallel to this boundary, successive cloud layers will be seen which are distinctly marked off, one from the other, by the size of their constituent molecules, sharp demarcations, and distinctness of colour. The colours come out particularly bright if a reduction of temperature be superinduced upon that caused by diminution of pressure, and a bluish glowing cloud appears at the top of the chamber to vanish again in a few seconds. The colour-changes in the several layers follow the same order from above downwards (as has already been described), in the central area with a continued fall of temperature. These colour-changes seem to have been observed by ALLUARD on the Puy de Dôme, when he reports (in 'Comptes Rendus,' vol. xcviii., p. 162), that "at sunrise and sunset we saw all the colours of the rainbow successively appear on the horizon in every direction." A splendid picture of cloud structure is given in the 'Leipzig illustrirte Zeitung' for March the 8th, from a sketch by PLUMANDON.

If the colour-producing cloud-layer has great vertical dimensions, diffraction rings will form round the sun and moon, especially when at low altitude. The diffraction rings round the sun may be observed, even when only faintly developed, by pasting a black disc about the size of the sun's image, on the back of a blackened glass, and looking at the sun with one eye in such a way that the sun shall be covered by the black disc.

POLARISCOPIC OBSERVATIONS BY M. CORNU.*

The corona has a considerable disturbing influence on atmospheric polarisation, especially near the neutral points. Since the appearance of the corona, the relative positions of the three neutral points have undergone considerable changes; moreover, four new neutral points have appeared which are situated in symmetrical pairs about the sun's vertical, nearly at the altitude of the solar and anti-solar centres. The two neutral points right and left of the sun can be readily seen by placing a piece of red glass between the polariscope and the eye (the face and the other eye should be well shaded); they are situated outside the red corona; a green glass shows the neutral points less distinctly, and a cobalt blue glass brings them close to the sun. The intensity of the perturbation decreases then with the refrangibility of the emitted light; the analysis of the polariscopic phenomenon, compared with that of preceding years, shows that the perturbation corresponds in each point to the superposition of a beam polarised in a plane perpendicular to a plane passing through the sun.

The new anti-solar pair of neutral points are, on the contrary, difficult of observation; it requires a double glass (*rouge à vitrail*), so as to work with a light as monochromatic and refrangible as possible. The field of view is dark; nevertheless the coloured bands are quite distinct when the sky is clear, but they can be seen for only a few minutes before sunset. There is a similar perturbation in the point of maximum polarisation, that is, at 90° from the sun in the vertical line. The maximum of polarised light, which on fine days might usually be represented by 0·75, has never exceeded 0·48; an accidental diminution in the amount of polarised light generally corresponds to a simple increase of haze; but the persistent low proportion which has prevailed under all meteorological conditions, taken in connection with the other disturbances, appears to indicate the existence of some cause which acts like haze in diffusing neutral light and diminishing the apparent polarisation of blue sky. Photometric measurements in the neighbourhood of the sun point to the same conclusion.

Polarimetric observations made with a red or a cobalt-blue glass show that the proportion of polarised light is less for the red than for the blue rays; here again the degree of disturbance diminishes with the refrangibility. This very summary account will not warrant any rigorous conclusions as to the cause of the phenomenon, but it suffices to show that it is probably related to the eruption of Krakatoa.

References in Section I. (E).

(¹) 'Nature,' vol. xxix. (1884), p. 260.
(²) 'Met. Zeitschrift,' vol. i. (1884), p. 58.
(³) MSS., dated December 8, 1884.

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[*] 'Comptes Rendus,' vol. xcix. (1884), p. 491, *et seq.*

(4) ‘Nature,’ vol. xxix. (1883), p. 103.

(5) ‘Standard,’ December 26, 1883.

(6) ‘Nature,’ vol. xxix. (1884), p. 251.

(7) ‘Quarterly Journal, Royal Met. Soc.,’ February 20, 1884.

(9) ‘Met. Zeitschrift,’ vol. i. (1884), p. 185.

(10) ‘Zeitschrift für Met.,’ Bd. xix., p. 72.

(11) ‘Nature,’ vol. xxix. (1884), p. 283.

(12) ‘Met. Zeitschrift,’ vol. i. (1884), p. 184.

(13) ‘Met. Zeitschrift,’ vol. i. (1884), p. 194.

(14) ‘Nature,’ vol. xxix. (1884), p. 403.

(15) ‘Comptes Rendus,’ vol. xcviii., p. 760, and vol. xcix., p. 446.

(16) ‘Comptes Rendus,’ vol. xcviii., pp. 1299, 1300.

(17) ‘Met. Zeitschrift,’ vol. i. (1883–4), pp. 196–198.

(18) ‘Comptes Rendus,’ vol. xcix., pp. 488–493.

(19) ‘Nature,’ vol. xxix. (1884), p. 260.

(20) ‘Nature,’ vol. xxix. (1883), p. 130.

(21) ‘Nature,’ vol. xxix. (1883), p. 103.

(22) ‘Comptes Rendus,’ vol. xcvii., p. 1515.

(23) ‘Nature,’ vol. xxix. (1884), p. 309.

(24) ‘Met. Zeitschrift,’ vol. i. (1884), p. 117.

(25) ‘Nature,’ vol. xxxi. (1885), p. 548.

(26) ‘Nature,’ vol. xxix. (1884), p. 503.

(27) ‘Quarterly Journal, Royal Met. Soc.,’ vol. x., April, 1884, and personal.

(28) ‘Comptes Rendus,’ vol. xcviii., p. 1299.

(30) ‘Nature,’ vol. xxx. (1884), p. 324.

(31) ‘Comptes Rendus,’ vol. xcix., p. 423.

(32) ‘Zeitschrift für Met.,’ vol. xix. (1884), p. 72.

(33) ‘Met. Zeitschrift,’ vol. i. (1884), p. 58.

(33a) Ship’s Log.

(34) ‘Am. Journ. Science,’ vol. xxvii., March, 1884, p. 204.

(35) ‘Met. Zeitschrift,’ vol. i. (1884), p. 57.

(37) ‘Nature,’ vol. xxx. (1884), p. 54.

(38) ‘Met. Zeitschrift,’ 1884.

(39) ‘Jamaica Weather Report’ for November, 1883, p. 5.

(40) ‘L’Astronomie,’ 3rd year, February 1, p. 67.

(41) ‘Quarterly Journal, Royal Met. Soc.,’ vol. x., p. 154.

(42) ‘Nature,’ vol. xxix. (1884), p. 525.

(43) ‘Hawaiian Monthly,’ May, 1884.

(44) ‘Met. Zeitschrift,’ vol. i. (1884), p. 117.

(45) Summary of a ‘Meteorological Journal’ for 1883.

(46) ‘English Mechanic,’ September 12, 1884.

(47) ‘Nature,’ vol. xxx. (1884), p. 488.

(48) ‘Nature,’ vol. xxx. (1884), p. 384.

(49) ‘Comptes Rendus,’ vol. xcix., p. 423.

(49a) ‘Nature,’ vol. xxxi. (1885), p. 192.

(50) ‘Proc. Mauritius Met. Soc.,’ October 27, 1883.

(51) MS. Letter addressed to Committee.

(52) ‘Nature,’ vol. xxix. (1884), p. 549.

(53) ‘Nature,’ vol. xxix. (1884), p. 309.

(54) 'Die Dämmerungserscheinungen und ihre physikalische Erklärung,' Leipzig, 1885.
(55) 'Proc. Mauritius Met. Soc.,' October 27, 1883, p. 11.
(56) 'Comptes Rendus,' vol. xcix., pp. 488–493.
(57) 'Nature,' vol. xxx. (1884), p. 359.
(58) 'Comptes Rendus,' vol. xcix. (1884), p. 423.
(59) 'Nature,' vol. xxx. (1884), p. 511.
(60) 'Comptes Rendus,' vol. xcviii., p. 760.
(61) 'Zeitschrift für Met.,' vol. xix., p. 72.
(62) 'Science,' vol. iii., p. 143.
(63) 'Comptes Rendus,' vol. xcviii., p. 760, and vol. xcix., p. 446.
(64) 'Comptes Rendus,' vol. xcviii., pp. 1299, 1300.
(65) 'Comptes Rendus,' vol. xcix., pp. 423–425.
(66) 'Nature,' vol. xxx. (1884), p. 463.
(67) 'Beobachtungen des rothen Sonnenringes, Dr. Kiessling,' p. 177.
(68) 'Met. Zeitschrift,' Bd. ii. (1885), p. 150.

PART IV., SECTION II.

GENERAL LIST OF DATES OF FIRST APPEARANCE OF ALL THE OPTICAL PHENOMENA.

By the Hon. ROLLO RUSSELL.

The following general list of exceptional optical phenomena comprises records from upwards of 800 localities, and has been compiled from all available sources. The Meteorological Council kindly allowed the writer full permission to search all the log-books sent in to their office; and Prof. Neumayer's papers in the 'Meteorologische Zeitschrift,' and Mr. Verbeek's 'Krakatau' also have been extremely useful. This section may in fact be regarded as the epitome of the facts which in subsequent sections have to be considered and explained.

The authorities are abridged as follows :—

Verb. Rep., or Verbeek's Report ..	'Krakatau,' by Mr. R. D. M. Verbeek.
Met. Office Log	Ship's special log at Meteorological Office.
Met. Zeitschr.	'Meteorologische Zeitschrift.'
Zeit. für Met., or Austrian Zeitschrift	'Zeitschrift der Oesterreichischen Gesellschaft für Meteorologie.'
S.S.R., or Signal Service Report ..	Monthly Weather Review of the U.S. Signal Office.

General List showing the Dates and Character of Celestial Appearances in different parts of the World in 1883 *and* 1884.

PLACE.	DATE.	NOTES.
Natal (Mr. Neison, 'Knowledge,' June 6, 1884).	Feb., &c., 1883	Fine sunsets, gradually increasing from February to June.
Brenhilda, about 25° S. to 30° S. 113° E. (Mr. Dove, MS.).	March 22, 1883.	On March 22 sun set in a sea of golden fire. Sky, delicate tints of blue and green.
Elisabeth .. .. (Tägliche Rundschau, Berlin; 'Met. Zeitschr.,' Verbeek's Report.)	May 20, 1883.	At 9 a.m., near the Straits of Anjer, a white column of vapour was seen to rise very rapidly above Krakatoa. The height, by measurement, was found to be 11,000 metres. Soon a fall of ashes, fine, grey, and slightly yellowish, occurred; and this continued till night of 21st. On the morning of the 21st the light resembled that seen during an eclipse; the sky was like a great dome of opal glass; the sun a pale blue globe. A fall of ashes also occurred at 346 English miles from Krakatoa, in a direction S.W.-½ W., with a S.E. wind. Dust was still observed in the air on the next few days.
Actæa—6° 50′ S., 101° 2′ E. (At noon, 21st, 8° 15′ S., 102° 28′ E., about 253 English miles from Krakatoa.) ('Brit. Assoc. Report,' 1885.)	May 20.	In the morning a peculiar light green colour in the E.S.E., and from E. to E.N.E. a dark blue cloud reaching from horizon to zenith. At 2 p.m. quite dark and a fall of very fine dust, which lasted till 9 a.m. on the 21st. On clearing, the sun looked like dull silver. Sky of a dusty hue till May 23rd.
Katimbang (Verbeek's Report)	May 20.	At 10 a.m. a column of smoke in the direction of Krakatoa. From 10 a.m. to noon on 21st, fall of ashes.
A. R. Thomas (Verbeek's Report).	May 20.	Eruption seen. Fall of ashes in morning, clouds of smoke rising over Krakatoa. The same phenomena observed by fishermen.
Zealand (Verbeek's Report) ..	May 20.	At 6 o'clock on this evening, being between Sebesi and Krakatoa, a black cloud was seen above Krakatoa, darting forth lightning incessantly. Rattle of explosions. Fall of ashes and stones.
Marathon—40° 49′ S. 80° 29′ E. (Met. Office Log.)	May 20.	Sky lighted up like early dawn at 9 p.m.
Tjerita (Verbeek's Report) ..	May 21.	Great cloud above Krakatoa. Loud explosions.
Kroë (Verbeek's Report) ..	May 21 to 23.	Fall of ashes, obscuring the sun.
Bandar; Bencoolen; Singapore; Telok Betong (Verbeek's Report).	May 21 to 23.	Detonations heard. At Telok Betong fall of ashes, May 21, 22.

PLACE.	DATE.	NOTES.
Moeara Doea (Verbeek's Report).	May 22.	In the afternoon the air was filled with fine particles, like pipe-clay.
Archer—5° 55′ S. 103° E. to 6° 5′ S. 104° 10′ E. (Verbeek's Report).	May 22.	From 6.30 a.m. to 1 p.m. fall of fine dust. Black cloud above Krakatoa.
Anjer	May 22.	Fire seen in the direction of Krakatoa.
Makasser, 14 miles south of Batavia.	May 22.	Great column of smoke, illuminated by lightning, seen this evening.
Tilkhurst—33° S. 29° E. (Met. Office Log).	May 22.	Clouds deep scarlet at sunrise. A hot glarish look all round horizon.
Conrad—Near south point of Krakatoa (Verbeek's Report).	May 23.	Thick rain of ashes and sulphur vapour. The smoke cut off sharply towards the east, but spreading out of sight towards the west.
Munich (Col. Ward, in Symons's 'Met. Mag.,' vol. xix., 1884, p. 22).	May 9, 11, 18, June 7, 12, 15, 21, July 20, Aug. 16.	Fine sunsets and after-glows.
Lord Warden, Captain Cooke—39° 18′ S. 93° 25′ E. (Met. Office Log).	May 24.	Sunset rather peculiar, dark blue-green tints on horizon.
Belfast—11° 38′ S. 31° 44′ W. (Met. Office Log).	May 24.	Clouds in west partly hiding zodiacal light.
Viola—16° 11′ N. 26° 55′ W. (Met. Office Log).	May 24.	At 4 a.m. sky almost cloudless; 8 a.m., overcast with a white haze, through which the sun is seen with a strong glare. 4 p.m., still hazy.
Tilkhurst—35° S. 25° E. (Met. Office Log).	May 24.	"At sunset a small patch of cirro-cumulus just over the sun, tinged a very lovely scarlet hue."
Belfast—16° 31′ S. 31° 40′ W. (Met. Office Log).	May 26.	Zodiacal light visible till after 8.30 p.m.
Her Majesty—3° 8′ S. 90° E. (Met. Office Log).	May 26.	At 9 p.m. thin haze over sky, through which larger stars show.
Viola—9° 59′ N. 28° 9′ W. (Met. Office Log).	May 27.	At 4 a.m. sky overcast with a layer of high stratus. At noon ropes and rigging found covered with a red dust. At 4 p.m. hazy all over; sun's disc very distinct and with very bright glare, like a pot of melted glass. On May 26, at 4 p.m., hazy all over. (? Sahara dust.)
Viola—7° 43′ N., about 28° W.	May 28.	Red dust over rigging.
Tilkhurst—35° 47′ S. 19° 35′ E. (Met. Office Log).	May 31.	Cirrus clouds, tinged deep scarlet to the eastward, long before sunrise.

Place.	Date.	Notes.
Switzerland (Col. Ward, Symons's 'Met. Magazine,' vol. xix., 1884, p. 22).	June.	Fine red sunsets on the Alps.
Hispania—36° N. 3° W. (Met. Office Log).	June 1.	Sky to west deep red at sunset.
Belfast—27° S. 28° W.	June 3.	Zodiacal light visible till after 8 p.m., and the light more open-hand shape than conical.
Belfast—31° S. 21° W.	June 7.	Small light clouds crossing sky before the wind. When the sun is at the back of these clouds, the edges are beautifully tinted, pink and green being the most noticeable colours.
Belfast—36° S. 5° 25′ W. ..	June 12.	Solar corona at 10 a.m.
Belfast—37° 26′ S. 1° 34′ W. ..	June 13.	A wind-dog above the sun and another to the right of the sun: these were portions of a very indistinct solar halo.
Belfast—38° 16′ S. 3° 58′ E. ..	June 14.	At 10 a.m. cirro-stratus, with tinted edges (green, pink, and orange), seen as each cloud passed over the sun, the sun being behind the cloud but near the edges of it. At 2 p.m. a solar halo (say 20°) and a corona at the same time. 8 p.m. some light cirrus passing over the moon caused a corona to be seen there. Similar colours in 36° 45′ S. 41° E. on June 22.
Anjer (Verbeek's Report) ..	June 19.	Krakatoa emitted much smoke. Thundering sounds. Two strong columns of smoke were seen to rise up majestically on the 24th when the intervening clouds were driven off by wind.
Belfast—37° S. 54° E. .. .	June 26.	At 8.15 p.m. a perfectly clear, dark sky, on which the zodiacal light is plainly seen, top about 32°.
Belfast—37° 34′ S. 62° 36′ E. ..	June 28.	Zodiacal light very distinct at 8 p.m.
Anjer (Verbeek's Report) ..	June 28 and 30.	Violent explosions and smoke in the night.
Belfast—36° 8′ S. 66° 47′ E. .	June 29.	Zodiacal light visible till after 9 p.m.
Belfast—29° 1′ S. 80° E. ..	July 3.	Zodiacal light visible till after 9 p.m.
Belfast—23° 24′ S. 81° 44′ E. ..	July 5.	Clouds with tinted edges near sun.
Viola—56° 28′ S. 66° 30′ W. (Met. Office Log).	July 11.	At 8 a.m. clouds of a brilliant red with a greenish sky to the N.E.
Belfast—5° 11′ N. 85° 27′ E. ..	July 15.	Hazy overhead.
Belfast—8° 52′ N. 85° 52′ E. ..	July 16.	6 p.m. An after-effect of the sun's setting was a bright yellow on the haze, which turns the dark green sea into a very pale green, and showed us a blue moon; this lasted 5 or 6 minutes.

PLACE.	DATE.	NOTES.
Belfast—11° 3′ N. 85° 53′ E. ..	July 17.	At 0·30 p.m. a very brilliant solar halo, which lasted about an hour, with varying degrees of brightness. Between the halo and the sun the sky was as dark as indigo; the colours of the halo itself, in their order, being brick-red, yellow, green, blue, and a broad outer border of a colour like polished steel. The sky was blue. 9 p.m. upper clouds from E.N.E. Another *blue* moon at sunset, seen through light haze.
Krakatoa (Verbeek's Report) ..	Aug. 11.	Enormous columns of smoke, reddish and dirty white. The products of the (May) eruption were found to have been deposited chiefly on the N.W. side.
Logansport, Indiana, U.S. ('S. S. R.').	Aug. 13.	Yellow sunset, with peculiar yellow band changing to red.
Madura (Verbeek's Report) .. ('Batavian Handelsblad' of August 16, 1883.)	Aug. 14.	Near Krakatoa, and even several miles from it, the air was full of ashes, and there was almost complete darkness. There were loud and continued reports.
Wilhelm—49° N. 7° W. ('Met. Zeitschrift,' vol. i., 1884, p. 157).	Aug. 16.	A strikingly deep and strong after-glow.
G. G. Loudon (Verbeek's Report).	Aug. 16.	In the morning, near Krakatoa, there was a dense rain of ashes.
Europa, near Krakatoa ('Met. Zeitschrift,' February, 1884).	Aug. 18.	Black clouds over Krakatoa. Fall of fine dust.
Natal (Mr. Neison, 'Knowledge,' June 6th, 1884).	Aug. 22.	Remarkable sunsets on August 21 and 22.
Nashville, Tennessee, U.S. ('Met. Zeitschrift,' Feb. 1884).	Aug. 22.	A beautiful sunset.
Scotia—A little east of Singapore (Met. Office Log).	Aug. 21, 23.	Zodiacal light seen.
Prinses Wilhelmina ('London and China Telegraph,' October 8, 1883).	Aug. 23.	Great column of smoke rose from the crater. Copious rain of ashes; flashes like lightning.
Medea ('Proc. Roy. Dub. Soc.')	Aug. 22 to 24.	While near Sunda Strait electrical phenomena and showers of sand and gravel.
Charles Bal—15° 30′ S. 105° E. (Captain Watson, 'Nature,' December 6, 1883).	Aug. 22.	At 8 p.m. in E. and N.E. a strong white haze or silvery glare. The same between 9 and 10 p.m.
Charles Bal (Captain Watson, 'Nature,' December 6, 1883).	Aug. 24.	Silvery glare.
Telok Betong (Verb. Rep.).	Aug. 25.	Fall of ashes in the evening.

Place.	Date.	Notes.
Prinses Wilhelmina—In Strait of Sunda (MS.).	Aug. 25.	About 7 p.m. " shakes and heavy blows in the distance, as from thunder, in W. and W.S.W."
Bay of Naples (Verbeek's Report).	Aug. 25, 26.	At 138 English miles south of Java's First Point (about 180 English miles from Krakatoa) explosions heard during the night of 25th–26th. On 26th sky extremely overcast and fall of ashes.
Airlie—0° 5′ S. 105° 9′ E. ('Met. Zeitschrift,' Feb., 1884).	Aug. 26.	Continual detonations. At 3 p.m. the whole ship shook.
Deli, Sumatra, 818 English miles from Krakatoa (Dr. Hagen, 'Nature,' January 10, 1884).	Aug. 26.	Thick white clouds "from the volcano Sipaiak," more than 20 miles distant.
Ruby, between Palembang and Singapore (Verbeek's Rep.).	Aug. 26.	Fall of ashes.
Medea ('Proc. Roy. Dub. Soc.')	Aug. 26.	At 2 p.m. first explosion heard. Then one every ten minutes. Column of dust rose at 2 p.m. to a height, given by one measurement at 17, and by another at 21 miles, the latter taken three hours after first explosion.
W. H. Besse—Near St. Nicholas Point, Java (Verbeek's Report).	Aug. 26.	At 4 p.m. sky threatening, atmosphere very close and smoky. 5 p.m. quick succession of heavy reports.
G. G. Loudon—In Lampong Bay (Verbeek's Report).	Aug. 26.	About 5 p.m. rain of ashes and pumice stones.
Charlotte—11° 7′ S. 107° 9′ E. ('Met. Zeitschrift,' Feb., 1884).	Aug. 26.	From 5 p.m. through the night loud thunderings and explosions.
W. H. Besse (Ship's Log, extract in Verbeek's Report).	Aug. 26.	Heavy reports throughout afternoon and night. Very dark and cloudy night, continual lightning.
Scotia—1° 34′ N. 103° E. (Met. Office Log).	Aug. 26.	Zodiacal light, 8 p.m.
Berbice—23 English miles S. of Vlake Hoek ('Sydney Morning Herald,' January 17, 1884).	Aug. 26.	At 2 p.m. dark threatening sky. At 6 p.m. rain of ashes. At midnight ashes mixed with small pieces of pumice.
Anjer ('Ceylon Observer,' September 6, 1883).	Aug. 26.	Pitch dark at 2 p.m.
Buitenzorg (Verbeek's Report).	Aug. 26.	Thunderings at 1 p.m.
Semanka (Verbeek's Report) . .	Aug. 26.	Fall of ashes in the evening.
Kroë (Verbeek's Report) . .	Aug. 26.	Loud detonations from 3 p.m.
Java's First Point (Verbeek's Report).	Aug. 26.	Sky quite overcast towards north at 2.30 p.m. At 6.10 p.m. fall of ashes.
5° 38′ S. 106° E.	Aug. 26.	Clouds red and yellow at sunset.

PLACE.	DATE.	NOTES.
Anerley—In the Straits of Banca, about 240 English miles N. of Krakatoa ('Nature,' November 8, 1883; Verbeek's Report).	Aug. 26.	In the forenoon heard a noise like distant cannonading; about noon the noise was more distinct. In the evening an arch of light rose, in a short time, from the horizon to the zenith. Three aneroid barometers rose and fell nearly an inch, at short intervals.
Charles Bal—In Strait of Sunda (Captain Watson, 'Nature,' December 6, 1883).	Aug. 26.	At noon, wind W.S.W., weather fine, dense black cloud above Krakatoa, which was quite hidden, except close to the water.
Ardgowan—7° 54′ S. 85° 37′ E. (MS., extract from Log).	Aug. 26.	Sky all of a flare at sunset. Wind, east. Course, north.
Lennox Castle—Equator, 91° 23′ E. (MS.).	Aug. 26.	At noon barometer fell from 30·20 to 29·90, and rose again as quickly in half an hour.
Jone—About 800 to 1000 English miles from Java, *i.e.*, 4° 46′ S. 90° E. to 7° 45′ S. 93° E. (Captain L. Reid, MS.).	Aug. 26 to 28.	Explosions heard and dust fell. The sun had a very strange appearance when rising; you would think the earth was on fire.
Barbarossa—1°·7 S. 93°·2 E. ('Met. Zeitschrift').	Aug. 26.	In the evening a dark bank in the S, and S.E.; whole sky peculiar red, like bright polished copper seen in bright daylight. This lasted 8 or 10 minutes and changed suddenly to uniform grey. During following night frequent, but strikingly short, thunder.
Foochow—26° N. 119° E. (MS. Report).	Aug. 26 and following nights.	Light, like aurora borealis.
Ceylon, Tissa Mahâ Râma, near N.E. coast (Mr. Parker, MS.).	Aug. 26.	Sounds of explosions heard day and night. First heard at 7 a.m. 26th.
Ceylon, whole of, except west coast (Mr. Parker, MS.).	Aug. 27.	Explosions heard. Heard as far west as Mannâr and Mullaittivu. Distance about 2000 English miles.
W. H. Besse—In Strait of Sunda (Verbeek's Report).	Aug. 27.	From daybreak a deep black cloud seen in the west, rising slowly, obscuring the sun and blackening the sky. Soon there was a fall of ashes, and most profound darkness during the day. Sun like a ball of fire on rising.
Norham Castle—66 English miles from Krakatoa (Mr. W. F. Stanley, 'Quar. Jour.' Royal Met. Soc., vol. x., 1884, p. 189).	Aug. 27.	Fall of ashes, 18 inches in 24 hours.
Telok Betong	Aug. 27.	Sky copper colour in the morning. Dark at 10.30 a.m.
Mullaittivu, Ceylon (Mr. Haughton, MS.).	Aug. 27.	Sky to east murky, and rays of sun obscured. From 4 p.m. sun green.
Kokkulai, Ceylon (Mr. Haughton, MS.).	Aug. 27 to Sep. 4.	Sun and moon blue colour.

PLACE.	DATE.	NOTES.
Semanka	Aug. 27.	Between 4 and 5 a.m. red illumination of a great extent of sky.
Anerley—92 English miles N.E. of Krakatoa ('Times,' Weekly Edition, October 12, 1883).	Aug. 27.	At 4.30 a.m. heavens lighted up pale yellow, of changing shades, lasting about 45 minutes. Daylight at 6 a.m. Total darkness part of the day. Showers of pumice till midnight.
Ardgowan—About 7° S. 85° 30′ E. (MS. from log).	Aug. 27.	Light wind, east to north. Second mate saw pumice falling.
Kroë	Aug. 27.	At 6 a.m. a greyish-yellow layer of dust covered everything. Sky grey and sun obscured. Smell of sulphur.
Straits of Banca, and Batavia..	Aug. 27.	Lurid skies.
Batavia (see 'Batavia Dagblad,' 'Ceylon Observer,' &c.; September 6 and 19, and November 2, 1883).	Aug. 27.	At 9 a.m. sky became darker, at 11 a.m. it became pitch dark and a fall of ashes began, sky dull yellow in west. Sun green on emerging.
Bantam—6° 12′ S. 106° 8′ E. ..	Aug. 27	At 11 a.m. pitch dark and shower of stones.
Serang, Bantam ('Ceylon Observer,' September 6, 1883).	Aug. 27.	Total darkness at 11 a.m. and all the morning. Stones falling.
H.M.S. *Magpie*—Labuan and Banguey Islands—5° 25′ N. 115° 18′ E. and 7° 19′ N., 117° 9′ E. (Captain Vereker, 'Nature,' December 13, 1883; also MS. Log).	Aug. 27?	Greenish sun and peculiar clouds to the southward for several days. The peculiar greenish hue of the sun lasted several days.
Tweed—Between Keeling Islands and Krakatoa, about 370 English miles from Krakatoa (Verb. Rep.).	Aug. 27?	Fall of ashes, 7 inches.
Sea Witch—Ashore at Sourabaya, Java.	Aug. 27.	Sounds as of heavy cannonading. Sun dim and smoky.
Simla—5° 35′ S. 88° E. (Met. Office Log).	Aug. 27.	8 p.m. very hazy. At midnight still very hazy.
Brani—3° S. 92° E. ('Nature,' November 8, 1883, Captain Perrot).	Aug. 27.	Showers of very fine sand, from midnight 27th till the 29th. Constant thunderings since 26th in direction of Sumatra.
Barbarossa—2°·6 S. 92°·9 E. ('Met. Zeitschrift').	Aug. 27.	Pale yellow sky at sunset, then extremely bright silver colour, then grey.
Charlotte—8°·3 S. 106°·7 E. ('Met. Zeitschrift').	Aug. 27.	From 8 a.m. till evening fall of ashes; 11 a.m., twilight; 2 p.m., dark.
Airlie—0° 32′ S. 105° 57′ E. (Captain Knight, 'Nature,' November 8, 1883).	Aug. 27.	Very early in the morning, fall of fine grey sand. From about 3 p.m., August 26, explosions.

PLACE.	DATE.	NOTES.
Prins Frederik—On 27th about 700 English miles W. of Krakatoa, *en route* for Europe (Verb. Rep.).	Aug. 27 to 29.	Rain of fine ashes.
Lennox Castle—About 4° S. 90° 30′ E. (MS.).	Aug. 27.	Light variable airs. Gloomy. Large quantities of pumice floating. Heavy showers of fine dust falling, which continued till September 1 in 10° 19′ S. 88° E.
Diego Garcia—7° 13′ S. 72° 23′ E. ('Proc. Met. Soc. of Mauritius').	Aug. 27 to 31.	At sunset strange appearance, deep purplish-red till 7.15 p.m. Sun partially obscured in the daytime.
Rodriguez and Cargados—19° 48′ S. 63° 10′ E. and 17° S. 60° E. ('Proc. Met. Soc. of Mauritius').	Aug. 27 to 31.	At Cargados, at sunset on 27th, smoky appearance westwards, and nearly up to the zenith. At Rodriguez on and since 27th, deep purplish-red in N.W. to 7.15 p.m.
Seychelles—4° S. 57° E. ('Proc. Met. Soc. of Mauritius').	Aug. 27.	Sky hazy all day. Sunset gorgeous, sky lurid all over, beams of red light.
Mauritius—20° 10′ S. 57° 35′ E. ('Proc. Met. Soc. Mauritius').	Aug. 27.	Sky overcast. Unusual dimness. Smoky appearance in west at sunset.
Burdwan—35° 40′ S. 21° 36′ E. (Met. Office Log).	Aug. 27.	Brilliant sunrise. 4 p.m., light cirrus and cirro-stratus from north.
Keeling or Cocos Islands—11° 50′ S. 96° 51′ E. (Mr Ross, Verb. Rep., p. 516).	Aug. 27.	From 4 p.m. on the 27th to midnight on the 29th, there was a fall of very fine dust, reaching a depth of half an inch.
Crowborough, Sussex (Mr. Prince, 'Met. Journal' of 1883).	Aug. 27.	Sunrise phenomena exactly like those of following winter.
Brani—4° 22′ S. 91° 34′ E. (Captain Perrot, see *ante*, p. 48).	Aug. 28.	From midnight to 11 a.m., a very large quantity of sand fell.
Kroë, Sumatra	Aug. 28.	Sky ashy-grey. Fine rain of ashes.
Simla—6° 12′ S. 88° 17′ E. (Met. Office Log).	Aug. 28.	At 2 p.m. sky very hazy, a fine white powder falling in a constant shower, like snow; whole ship covered with it. 8 p.m., sky still very hazy and dust falling. It looks like pumice ground into flour.
Salazie — 9° 15′ S. 93° 1′ E. ('Comptes Rendus,' No. 21, Nov. 19, 1883).	Aug. 28.	Shower of sand in early morning, 5.30 a.m. Sky white. Sun reddish-yellow. Sand till 29th.
County of Flint—8° 20′ S. 92° 4′ E. (Captain Rowland, 'Nature,' November 8, 1883).	Aug. 28.	Great quantity of dust falling at noon.
Barbarossa—3°·8 S. 93°·5 E. ('Neues Jahrbuch für Mineralogie,' 1884, ii., p. 32).	Aug. 28.	Before daylight, and throughout the day, fall of fine grey ashes.

Place.	Date.	Notes.
Ida—1°·3 N. 108° E. ('Met. Zeitschrift').	Aug. 28.	Since this date, uninterrupted hazy air. Sun set red.
Charlotte—7°·3 S. 106°·2 E. ('Met. Zeitschrift').	Aug. 28.	Hazy air.
Arabella—1127 English miles west of Java Head; 5° 37′ S. 88° 58′ E. at noon on 28th ('Nature,' December 13, 1883).	Aug. 28.	"It began to rain something like sand in the morning." Continued throughout 28th and 29th. Wind light, W.S.W. on 28th, calm at times.
Scotia (Captain Cato)—6° N. 95° E. (Met. Office Log).	Aug. 28.	At noon halo round sun, complete circle. 4 p.m., lower clouds from S.W. No mention of glows.
Seychelles (Mr. Estridge, 'Nature,' November 8, 1883, and July 17, 1884).	Aug. 28.	Sun seen as through a fog, at sunset. At 5 p.m., sun clear and bright. A lurid glare all over the sky after sunset. At 6.30 p.m. much brighter, at 6.45 it disappeared.
Diego Garcia and Cargados (M. Lecomte, 'Nature,' November 8, 1883, and July 17, 1884).	Aug. 28.	Sun obscured, strange sky. At Cargados, when day dawned, there was a peculiar crimson coloration from E. by N. to S.E. by E., and the sun, after rising, showed as if seen through the red shade of a sextant.
Rodriguez (Mr. Wallis, 'Nature,' July 17, 1884).	Aug. 28.	Strange red threatening sky at sunset.
Mauritius (Dr. Meldrum, 'Proc. Met. Soc. of Mauritius').	Aug. 28.	Crimson dawn. Sun red after rising. Gorgeous sunset, first of the after-glows. Sky and clouds yellow and red up to zenith.
Natal (Mr. Neison, 'Knowledge,' June 6, 1884).	Aug. 28, 29.	Most vivid sunsets; also August 31 to September 5, sky vivid red, fading into green and purple.
Emma Römer—25° S. 61°·5 E. ('Met. Zeitschrift').	Aug. 28.	Sky bright in the south in the evening.
Castleton (Captain Dioré)—5° 58′ S. 93° 30′ E. (Verbeek's Report).	Aug. 28.	At 2 a.m. air loaded with fine dust which fell in great quantities. Still falling at 2 p.m.
Tokio, Japan—35° 43′ N. 139° 43′ E. ('Japan Gazette,' 'Nature,' April 3, 1884).	Aug. 28.	On this and following days, sun copper colour and rayless. Blood-red at Yokohama.
Earl Beaconsfield—From England to Calcutta *viâ* the Cape (MS., September 23, 1883). Date and latitude and longitude not stated, but probably about 5° S. and 90° E., on 28th.	—	"One morning we woke up to find everything covered with lava, and any amount of pumice stone floating round us. It lasted 4 days. You could not keep the dust out anywhere. At that time we were 900 miles from the nearest volcano (Sumatra)."
Ardgowan—6° 37′ S. 85° 21′ E. (MS. from log).	Aug. 28.	Wind light and variable, S.W. to S.E. Saw pumice floating.

PLACE.	DATE.	NOTES.
Yokohama (Mr. W. Hamilton, 'Nature,' December 13, 1883).	Aug. 29.	Sun blood-red, with jets like smoke passing across its face. Lasted two days.
British Empire—2° 37′ S. 79° 52′ E. ('Ceylon Observer,' October 2, 1883).	Aug. 29.	From afternoon of 29th to end of 30th sun nearly obscured by pale yellowish haze, and a considerable fall of light dust, like Portland cement. Light wind, S.E. to S.W.
Simla—6° 26′ S. 87° 52′ E. (Met. Office Log).	Aug. 29.	A very large quantity of dust fell in the past night. At 4 p.m., very hazy still, and dust falling. At 5 p.m., sun completely obscured 15° above the horizon, owing to haze. 8 p.m., dust still falling.
Coppename—15° 30′ N. 57° 30′ W. (Met. Office Log).	Aug. 29.	"Clouds appear dry, smoky, indescribable" at 8 p.m.
Amelia—44°·6 N. 52°·9 W. ('Met. Zeitschrift').	Aug 29.	Sky at sunrise all imaginable colours; small spot in S.E.
Cheefoo—37° 24′ N. 121° 25′ E. (MS. Report of Lighthouse).	Aug. 29.	Pale red glow, like a fire.
Scotia—5° N. 90° 40′ E. (Met. Log Office).	Aug. 29.	8 a.m., upper clouds high and slow, from E.N.E., wind S. by W., and lower clouds W.; complete circle round sun at noon. At 8 p.m., zodiacal light and radiance to eastward.
Mauritius (Dr. Meldrum, Met. Soc. of Mauritius Report).	Aug. 29.	Fiery sky before sunrise.
Lord Warden—55° 56′ S. 62° 51′ W. (Met. Office Log).	Aug. 29.	At sunset the sky presented a brilliant spectacle; at a considerable altitude west and east the cirro-stratus was tinted with a delicate rose colour. Close down on the western horizon streaks of pale green and yellow, the whole covered with a haze of roseate hue.
Ardgowan—5° S. 85° E. (Mr. W. Hamilton, and MS. from log).	Aug. 29.	Dust falling from 7 a.m. At 8 a.m., great masses of pumice floating. Sun appearing of a reddish hue through mist that surrounded it. Wind E. Midnight, fall of rain, greenish matter falling with it, covering deck like ash dust.
Fisher Island—23° 32′ N. 119° 28′ E. (MS. Lighthouse Report).	Aug. 30.	About August 30, and for 4 or 5 days, fiery glow about 20 minutes after sunset.
Emma Römer—26°·5 S. 56°·5 E. ('Met. Zeitschrift).	Aug. 30.	Sunset lovely colours, ending with purple.
Simla (Captain Nicholson)—7° 19′ S. 87° 26′ E. (Met. Office Log).	Aug. 30.	Very hazy and dust falling.
Scotia—4° 9′ N. 86° 40′ E. (Met. Office Log).	Aug. 30.	At 8 a.m., upper clouds high and slow from E. by N. Diverging rays and zodiacal light at sunset.

PLACE.	DATE.	NOTES.
Ida—1°·3 N. 108°·4 E. ('Met. Zeitschrift').	Aug. 30.	Sun seen as through a veil.
Meda—Off north-west Cape of Australia, about 1150 English miles S.S.E. of the Strait of Sunda ('Nature,' December 13, 1883).	Aug. 30.	Quantities of volcanic dust fell in the past night, that is between sunset 30th and sunrise 31st. Wind on shore.
Tokio and Yokohama, Japan ('Japan Gazette,' 'Nature').	Aug. 30.	Soon after noon the sun became dim; a yellow haze spread over the sky; and on the 31st the sun was like the moon. On August 30 and 31 pale moon-like sun at Yokohama.
St. Helena—16° S. 5° 44′ W. (MS. from Governor).	Aug. 30.	Red light like distant fire, deep red in S.E. and S.W. at 4 a.m.
Corona (Captain Shearer)—2° 40′S. 20°W. (Met. Office Log).	Aug. 30.	A lurid glare in the sky at sunset, objects looking a ghastly blue.
German ship—10° N. 26° W. (MS. letter).	Aug. 30.	Remarkable leaden sky after sunset.
Maranham, Brazil—2° 30′ S. 44° W. ('Met. Zeitschrift').	Aug. 30.	Remarkable sunset.
Rivas, Nicaragua, Central America (Dr. Earl Flint; S. S. R.).	Last days of Aug. and first of Sept.	Blue sun in South America.
Nikko, Japan (Prof. J. M. Dixon, 'Nature,' December 27, 1883).	Aug. 30 and 31.	Sun copper colour with no brightness during the two or three days at the end of August. Popular alarm manifested.
Maranham ('Nature,' November 22, 1883).	Aug. 31.	Sun dim at 7 a.m. Pale sun August 31 to September 6.
Para—1° 28′ S. 48° 24′ W. (Dr. van Rijckevorsel, 'Met. Zeitschrift').	End of August.	Fiery after-glows.
Natal (Mr. Neison, MS.) ..	Aug. 31.	Vivid red sky; green and purple in the east. Continued most remarkable on September 1, 2, 3, and 5.
Emma Römer—25° S. 55°·7 E. ('Met. Zeitschrift').	Aug. 31.	Splendid sunset but less brilliant than on the 30th.
2° S. 5° E. ('Met. Zeitschrift') .	Aug. 31.	The dark-red sun had a white and silvery sheen.
Albert Reimann—2°·3 S. 4°·7 E. ('Met. Zeitschrift').	Aug. 31.	Sun veiled with a silver-white sheen.
Aux Cayes, Hayti—18° 30′ N. 71° 20′ W. ('Met. Zeitschrift,' 1884, p. 181).	From the end of Aug. to March 1, 1884.	Perpetual haze or dense veil round the sun.
Scotia—About 3° N. 83° E. (Met. Office Log).	Aug. 31.	Zodiacal light.

PLACE.	DATE.	NOTES.
Olbers—3° 5′ N. 27° 6′ W. (Met. Office Log).	Aug. 31.	Clouds, light towards sundown (visible).
British Envoy—13° 30′ N. 31° 20′ W. (Met. Office Log).	Aug. 31.	Curious electric light appearance in the sky, quarter of an hour before sunrise, and the same about half an hour after sunset. Much cirrus about east and west horizons at each time. Sky opposite quite dark by contrast.
Corona—1° 20′ S. 21° W. (Met. Office Log).	Aug. 31.	At 8 a.m. a metallic sort of haze over the sky, the sun shining through it quite coppery. At 5 p.m., in about 0° 10′ S. 21° W., sun still of a coppery appearance.
Marathon—49° 49′ S. 175° 19′ W. (Met. Office Log).	Aug. 31.	Deep red in west horizon at sunset.
Cape Coast Castle—5° N. 0° W. ('Gold Coast Times,' September 14; see 'Times' of December 5, 1883).	Sept. 1.	Sun rose like the moon. Clouds passing gave it different colours, rose colour, pink, &c.
Frieda Grampp—12°·7 S. 27°·3 W. ('Met. Zeitschrift').	Sept. 1.	Sun lead colour at setting.
German ship—10° 40′ N. 26° 30′ W. (MS.).	Sept. 1.	Sun blue from sunrise to 7 a.m., pale later on.
Queen of Cambria—9° S. 28° W. (Met. Office Log).	Sept. 1.	At 8 a.m. a peculiar thin haze in the air, through which the sun is seen with a clearly defined circumference, and almost white in colour. At 8 p.m. stars dimly visible through the haze.
Earnock (Captain Parson)—11° N. 25° 30′ W. (Met. Office Log).	Sept. 1.	4 a.m., eastern sky, before sunrise, silver-grey, changing to light blue, flecked with numerous small cirrus trimmings, pink and rosy.
Guayaquil—2° S. 80° W. (M. E. Mareuse, in 'L'Astronomie').	Sept. 1.	From September 1 to 5, a light, copper-coloured, atmospheric veil. Sun shining so feebly that it could be seen with naked eye from 4 p.m., like a disc of silver upon a golden background; the spots also could be seen with the naked eye.
Santiago, Chili—33° S. 71° W. ('Met. Zeitschrift,' March, 1884).	From about Sept. 1 for several months.	Red glows more than one hour before sunrise, and after sunset. "Several hours," according to Herr K. Rudolph.
New Ireland—3° S. 152° E. (Captain Tierney, of *Hazard*; 'Nature' January 17, 1884).	Sept. 1.	Sky-glow or glare.
Frieda Grampp—10°·2 S. 27°·2 W. ('Met. Zeitschrift').	Sept. 2.	The sun rose like a lead plate, and remained rayless till near 8 a.m. The whole sky was grey, the sun appearing like polished lead.
Carupano—10° 36′ N. 63° 16′ W.	Sept. 2.	Sun, on rising, blue, and during the day. Splendid colours after sunset.

Place.	Date.	Notes.
Varinas, Venezuela—8° 6′ N. 70° W. (Mr. Hyde Clarke, 'Nature,' November 22, 1883).	Sept. 2.	Sun like burnished silver from sunrise to noon, and from 3 p.m. to sunset. From noon to 3 p.m., bluish-green.
Maracaybo—11° N. 72° W. ('Met. Zeitschrift').	Sept. 2.	Blue sun.
Paramaribo—6° N. 55° W. (Dutch paper, Herr Metzger, 'Nature,' January 10, 1884).	Sept. 2 (?)	Blue sun.
Bogotà—4° 43′ N. 74° 12′ W. (Met. Zeitschrift').	Sept. 2.	Blue sun.
Panama—8° 59′ N. 79° 32′ W. ('Nature,' December 13, 1883).	Sept. 2, 3.	Green sun.
Ecuador—3° S. 76° 30′ W. ('Met. Zeitschrift').	Sept. 2.	Blue sun.
St. Thomas, West Indies—18° N. 65° W.	Sept. 2.	Blue sun.
Peru ('Met. Zeitschrift') ..	Sept. 2.	Blue sun.
San Christobal—7° 30′ N. 72° 23′ W. ('Met. Zeitschrift')	Sept. 2.	At 3 p.m. the sun suddenly lost its lustre and turned blue. Red light after sunset.
Cartagena, Colombia—10° 22′ N. 75° 32′ W. ('Met. Zeitschrift').	Sept. 2.	On this and following days the sun set green.
Medellin—6° 2′ N. 75° 49′ W. ('Met. Zeitschrift').	Sept. 2.	Sun lustreless and green, then blue, and, lastly, violet. A long belt of vapours along western sky.
Trinidad, Port of Spain—10° 30′ N. 61° 20′ W. (Mr. Arnold in 'Times').	Sept. 2.	Sun looked like a blue ball, and after sunset the sky became so red that there was supposed to be a great fire.
Rosario—3°·7 N. 29° W. ('Met. Zeitschrift').	Sept. 2.	Hazy air in afternoon. Grey sky.
Emma Römer—36° S. 21° E. ('Met. Zeitschrift').	Sept. 2.	Splendid twilight colours.
Argentina—12°·1 S. 36°·9 W. ('Met. Zeitschrift').	Sept. 2.	Soon after noon hazy-looking air, the sky quite grey.
Cebu and neighbouring districts ('Straits Times,' in 'Ceylon Observer,' November 15, 1883).	Beginning of September.	Blue sun and moon.
Queen of Cambria, 5° 25′ S. 27° 27′ W. (Met. Office Log).	Sept. 2.	Same haze as on September 1.
Olbers—4° 41′ S. 31° 10′ W. (Met. Office Log).	Sept. 2.	Noon, sun obscured at intervals. At 5 p.m. sun visible through clouds, pale blue.

PLACE.	DATE.	NOTES.
H.M.S. *Magpie* (Captain Vereker, Dent Haven, North-east Borneo; Met. Office Log).	Sept. 2.	Bright orange sky at sunset.
Olbers—About 7° S. 33° W. (Met. Office Log).	Sept. 3.	At 4 a.m. northern horizon very red. At 7 a.m. strange appearance of sun, clear pale-blue colour.
Maracaybo—10° 38′ N. 71° 38′ W. ('Met. Zeitschrift').	Sept. 3.	Azure sun.
Medellin ('Met. Zeitschrift') ..	Sept. 3.	Same phenomena at sunrise as on 2nd at sunset, but in inverse order. Sun rose violet, then became blue, then green.
Euterpe—14° S. 7°·9 W. ('Met. Zeitschrift').	Sept. 3.	Grey cloud stratum above the cumulus and stratus clouds, and covering whole sky, during the last few days.
Argentina—8°·2 S. 34°·6 W. ('Met. Zeitschrift').	Sept. 3.	At noon hazy grey air. Hazy, grey, damp air towards evening.
Scotia—1° 37′ N. 71° E. (Met. Office Log).	Sept. 3.	8 a.m., hazy overhead. Wind S. by W.
Burdwan—26° 43′ S. 8° 35′ E. (Met. Office Log).	Sept. 3.	Magnificent sunset. Long twilight. Upper clouds from N.W.
Cape Town, South Africa—34° 56′ S. 18° 27′ E. (MS.).	Sept. 3.	Glows began. At 6.50 p.m. the western sky was lit up as by a conflagration. It began at 6.30, more than one hour after sunset, and vanished at 7.15. After this date the glows diminished till about the 20th, when they again became striking.
Queen of Cambria—3° 6′ S. 27° 4′ W. (Met. Office Log).	Sept. 3.	"Before sunrise the haze that is still in the air was fiery red, and the sun, when it appeared, was of a dazzling white colour." Course of ship northerly.
C. Southard-Hurlburt—about 17° N. 125° W. (Captain Davis, 'Nature,' April 10, 1884).	Sept. 3.	Most brilliant after-glow.
New Hanover—3° S. 150° E. (*Hazard*; 'Nature,' January 17, 1884).	Sept. 3.	Bright and remarkable glow after sunset.
Olbers—11° 30′ S. 36° 44′ W. (Met. Office Log).	Sept. 4.	Sunset fine.
Euterpe—13°·6 S. 9°·9 W. ('Met. Zeitschrift').	Sept. 4.	Sun like the moon. Four rings round sun.
Jennie Walker—8° 20′ N. 155° 28′ W. ('Nature,' April 10, 1884).	Sept. 4.	Strange appearance at 5 p.m., sun greenish. Sun green at setting. Strange colours in west.
Fanning Island—3° 30′ N. 159° 13′ W. (Mr. Greig, 'Nature,' April 10, 1884).	Sept. 4.	Sun in afternoon like copper.

PLACE.	DATE.	NOTES.
Superb—Mr. Dove (MS.) ..	Sept. 4.	Remarkable sunset; before the red after-glow had faded, the moon rose in the dark blue sky, making quite an Italian picture.
Superb (Captain)—16° 5′ S. 148° 45′ W. (Met. Office Log).	Sept. 4.	At sunset, bank of stratus along N.N.E. horizon, and quantities of stationary cirri along N.W. horizon.
Papa—10° 19′ N. 161° 21′ W. (Captain Bannau; 'Met. Zeitschrift,' and MS.).	Sept. 4.	In the morning "the sky is covered with a thin white layer. The sun penetrates it. Atmosphere looks yellow and watery. Few lower clouds." (Date given, 5th, by Eastern time.)
Tapiteuea—1° 10′ S. 174° 50′ E. (Mr. Bishop, informed by Mr. F. L. Clarke, MS.; Mr. Clarke's letter to 'Honolulu Advertiser').	Sept. 4 or 5? (Western time). Sept. 5 or 6? (Eastern time).	For several days before September 7th (*i.e.*, 6th, Western time), sky covered with a light haze, and sun like a clear silver disc. At 6 a.m. sun can be viewed with naked eye.
Colombo, Ceylon—7° N. 80° E. ('Ceylon Observer').	Sept. 4.	Strongly tinted zodiacal light at 7.15 p.m.
Burdwan—25° 51′ S. 7° 49′ E. (Met. Office Log).	Sept. 4.	Grand sunrise. Clouds from west.
Maracaybo	Sept. 5.	Azure sun.
Colombo, Ceylon (correspondent of 'Standard').	Sept. 5.	Sun green and very dim at 5 p.m., like the moon. In declining, it changed from yellowish-white to pea-green.
Queen of Cambria, 1° 37′ N. 26° 12′ W. (Met. Office Log).	Sept. 5.	Haze, similar to that observed on 3rd, in the air again to-night.
Transvaal; Roefontein, Wakkerstroom (Mr. Ballot, 'English Mechanic,' May 2, 1884).	Sept. 5.	Glows first observed. Generally observed from September 7. Began greenish-yellow, or with a bluish-white glare, then red appeared above, and purple and violet. Disappeared from 1 to $1\frac{1}{2}$ hours after sunset. Secondary glow duller than the first. Most vivid till January. [See also Graaf Reinet, September 20.]
Natal (Mr. Neison, 'Knowledge').	Sept. 5.	The extraordinary sunsets not seen after this date till January, except faintly.
Ceylon (Mr. Parker, MS.) ..	On or about Sept. 5, 6, 7, and 8.	Magnificent sunsets. Sky peculiar and varying colours, blue and reddish-purple. During this week the weather was peculiar, with white and leaden coloured clouds.
Carola—4°·8 S. 15°·5 W. ('Met. Zeitschrift').	Sept. 5, 6, and 7.	Strangely coloured sky, green in east, red in west. Lasted till 1 hour 30 minutes after sunset.
Olbers—Bahia, Brazil—13° S. 38° 30′ W. (Met. Office Log.)	Sept. 5.	Sky glaring red to the northward at 4 a.m.
Scotia—About 4° N. 62° E. (Met. Office Log).	Sept. 5.	Green moon in bright blue sky, above glowing light red cirro-stratus. Clouds passing over moon also green. Rare and very beautiful sight, 7 p.m.

PLACE.	DATE.	NOTES.
Argentina—0°·1 N. 30°·4 W. ('Met. Zeitschrift').	Sept. 5.	Ashy-grey atmosphere at sunrise.
Honolulu—22° N. 158° W. (Mr. Bishop, Mr. and Mrs. Whitney, MS. and 'Nature,' April 10, 1884).	Sept. 5.	Sun set green. Remarkable after-glow first seen. Secondary glow lasted till 7.45 p.m. Gold, green, and crimson colours. Corona constantly seen from September 5 to December 15. Misty rippled surface of haze.
Steamer—3 days S. of Honolulu (Dr. G. F. Burder, 'Times,' December 18, 1883).	Sept. 5.	"We witnessed a most curious phenomenon. The sun set perfectly blue, and next morning it rose a flaming ball of blue."
Maalaea, Maui, Sandwich Is. (Mr. Atwater, 'Nature,' April 17, 1884.)	Sept. 5.	Wonderful red glow in the early morning.
Zealandia—About 5° N.; between Honolulu and the Equator. (Mr. Bishop, 'Nature,' October 2, 1884.)	Sept. 5.	Sun rose blue.
Superb (Mr. Dove's MS.) ...	Sept. 5 to 8.	Sun like a silver ball. Hazy sky. Curious haze high up in the air.
Superb—13° 17′ S. 148° 46′ W. (Met. Office Log).	Sept. 5.	6 a.m., cirrus in lines from N.W. by N. to S.E. by S. moving from N.W. by N.; noon, sky full of haze or a sort of thin cirro-stratus, but owing to glare could not distinguish which. At 6 p.m. cirro-stratus in lines from W.N.W. to E.S.E. drifting from W.N.W.; muddy looking.
Papa—8° 1′ N. 161° 4′ W. (MS.)	Sept. 5.	Whole sky covered with uniform yellowish-red high cirro-stratus. Sun quite pale with definite rim, as through blue glass, without burr or halo.
Nashville, Tennessee, U.S. (Signal Service Report.)	Sept. 5, 6.	Sunset, shadows very bright.
Strong Island—5° N. 163° 6′ E. (Miss Cathcart, 'Nature,' October 2, 1884.)	Sept. 6 (Sept. 7 by Eastern time).	Very peculiar appearance of sun. Sky somewhat cloudy. Silvery pale blue sun, which could be gazed on. No bright sunshine all day.
Gilbert Islands—0·0 172° E. (Mr. F. L. Clarke, 'Nature,' October 2, 1884).	About Sept. 6 (Sept. 7 by Eastern time).	Obscured and coppery sun.
Papa—5° 39′ N. 160° 31′ W. (Captain Bannau, MS.)	Sept. 6 (Western time).	Yellowish coloured sky. Moon and stars shine through.
Superb (Captain)—10° 17′ S. 148° 40′ W. (Met. Office Log).	Sept. 6.	At 6 a.m. beautiful finely mottled cirro-cumulus, stretching almost across sky from E.S.E. At noon sky full of dense haze so that the sun, as it approached the horizon, at an altitude of 10° or more, looked like a silver ball.
Carola—4°·8 S. 15°·5 W. ('Met. Zeitschrift').	Sept. 6.	Sky peculiarly coloured at sunset, east green, west red. Red in west visible till 1h. 30m. after sunset.

Place.	Date.	Notes.
Thessalus—36° 33′ S., 66° 28′ E. (Met. Office Log).	Sept. 6.	Most magnificent sunset.
Ida—2°·7 S. 107°·2 E. ('Met. Zeitschrift').	Sept. 6.	Hazy air, very opaque.
Bahia, *Olbers*—12° 56′ S., 38° 27′ W. (Met. Office Log.)	Sept. 6.	Sky glaring red at 3 a.m.
Scotia—5° 52′ N. 59° E. (Met. Office Log.)	Sept. 6.	8 a.m. Very fine sand deposited in places exposed to the wind.
Scotia—8° 5′ N. 55° 16′ E. (Met. Office Log.)	Sept. 7.	Hazy round horizon. Very fine sand deposited in places exposed to the wind. Wind S.S.W. force 4 to 6. Upper clouds from N.N.E.
Ida—4°·7 S., 106°·3 E. ('Met. Zeitschrift').	Sept. 7.	Very hazy air.
Olbers—16° 50′ S. 38° 17′ W. (Met. Office Log).	Sept. 7.	Sky glaring red at 5 a.m.
Carola—About 6° N. 16° W. ('Met. Zeitschrift').	Sept. 7.	At sunrise, like sunset yesterday (see p. 279). The sky seemed filled with uniformly distributed small misty clouds.
Superb—7° 47′ S., 148° 40′ W. (Met. Office Log).	Sept. 7.	Dense haze all over the sky, as yesterday.
Cienfuegos—At Nassau, New Providence, Bahamas (Captain Faircloth; Signal Service Report.)	Sept. 7.	The sun at setting on September 7 cast a lurid glare over the western sky.
Tapiteuea (MS., Mr. Bishop, from Mr. F. L. Clarke; also 'Honolulu Advertiser').	Sept. 8. (Eastern time.)	Sun like tarnished silver. Beautiful display of curious clouds, from eastern horizon to zenith, in fine lines, overlaid at an angle of 45° with others.
Virginia, U.S. (Mr. W. G. Brown, 'Nature,' January 24, 1884).	Sept., early in.	Glows seen. Once in October.
Florida ('Met. Zeitschrift'). ..	Sept. 8.	Red sunset.
Haslemere, Surrey (Hon. Rollo Russell, MS.)	Sept. 8.	Bright after-glow noted, and fine red sunset.
Chelsea, London (Mr. Ascroft, MS.)	Sept. 8.	Unusual after-glow noted.
Réunion (M. Pélagaud, 'Comptes Rendus,' January 28, 1884.)	Sept. 8.	Wonderful glow from this date. Zones of colour from horizon after sunset, green, yellow, orange, red, blue sky. From the middle of December it rapidly diminished.
Réunion	Sept. 8.	Illumination of sky increasing daily.
Superb—5° 30′ S. 148° 27′ W. (Met. Office Log.)	Sept. 8.	Sky full of dense haze, attended by same phenomena as on the 6th.

Place.	Date.	Notes.
Rio Grande—From New York to Galveston (Captain Burrows; Signal Service Reports).	Sept. 7 to 9.	For several hundred miles outside its (the storm's) approaching periphery, the sunsets were yellow, and the reflection on the clouds in the east was fiery red; while the rising of the sun was characterised by a startling redness of the eastern sky (always considered a sign of bad weather). The stars presented a "sprawling or spattered" appearance; while the young moon was seen surrounded by a vapory halo of continually changing density. [The ship left New York at 10 p.m. on September 5; and at 5 a.m. on September 9 was 55 miles S.S.E. of Canaveral in about 28° N. 80° W. The storm passed to the east of the ship].
Lead Hill, Arkansas, U.S. (Signal Service Reports).	Sept.	Brilliant sunsets from September to the end of January, when they were declining.
Somerset, Mass., U.S. (Signal Service Reports).	Sept.	Beautiful sunsets in September and October.
Virginia, U.S.A. (Mr. W. G. Brown, 'Nature,' January 31, 1884).	Early in Sept.	After-glow first noticed.
Ida—5°·5 S. 106°·1 E. ('Met. Zeitschrift').	Sept. 8, 9.	Hazy air; sun set as a yellow disc.
Scotia—10° N. 53° E. (Met. Office Log).	Sept. 8.	Hazy round horizon. Still a deposit of sand found. Partial halo forming at times round the sun. Wind S.S.W., force 7, upper clouds N.E., rather high and slow. Moon green before setting.
Colombo, Ceylon ("W" in 'Nature,' November 1, 1883).	Sept. 9.	Sun green in afternoon, about half as bright as the moon.
Iloilo, Manilla—10° 30′ N. 122° E. ('Comercio,' newspaper, Manilla; see 'Ceylon Observer,' November 5, 1883).	Sept. 9, 10.	Greenish sun, like the moon. Nothing of the kind ever before seen by the fishermen.
Papa—0°·1 S. 163°·7 W. (MS., Captain Bannau).	Sept. 9.	Sky at 8 a.m. still thinly veiled, and sun's rays tempered. Sun disappeared at 7° altitude in the yellow stratum in the west. Clear lower air.
Pelican—10° 4′ N., 64° 13′ E. ..	Sept. 9.	Sun blue near zenith, green lower. Moon greenish in night of 9th. Sun green, 10th.
Paul Rickmers—34°·6 S. 17°·2 E. ('Met. Zeitschrift').	Sept. 9.	Air very hazy, sun set dark-red.
Ceylon ('Ceylon Observer') ..	Sept. 9.	Sky murky red, and sun pale blue, blueness increasing in intensity towards setting.
Madras (Michie Smith, 'Nature,' November 8, 1883).	Sept. 9 to 11.	On September 9, sun silvery and rayless. On September 10, green at 5.43. On 11th, bright green 5.30. Brilliant sunset effects lasting 1 hour. Moon and stars green.

PLACE.	DATE.	NOTES.
8° to 16° N., and 87° 30′ to 88° 44′ E. (MS.).	Sept. 9, 10, 11.	Sun of bright vivid green on rising and setting.
Belfast—16° 56′ N. 87° 17′ E. (Met. Office Log).	Sept. 9.	Light brown clouds near sun all day. Two hours before sunset, sun pale blue, like the moon, and not more difficult to look at.
Lord Warden—37° 6′ S., 40° 46′ W. (Met. Office Log).	Sept. 9.	The sun surrounded by a haze of pale yellow tint at noon. From 6 p.m. "the most wonderful sunset I ever beheld; observed colours I never saw before. The whole of the heavens a steel-grey tint, and all the brilliant colours faded away into the same grey. Observed a large halo round the moon which was quite blue at sunset."
Cleomene—8° to 16° N. 83° 30′ E. to 88° 40′ E. (Captain, and Prof. Michie Smith in 'Nature,' August 7, 1884).	Sept. 9, 10, 11.	Green sun and moon.
Scotia—About 12° N. 51° E. (Met. Office Log).	Sept. 9.	Sun green on rising; moon green before setting. From 8th to 11th sky covered with a thin cirro-stratus haze.
Wellington, N.Z.—41° S. 175° E. (Dr. Hector, F.R.S., MS.).	Sept. 9.	Splendid sunsets began and continued till January 31, 1884, with striking effects.
Ascension Island (MS., Governor).	Sept.	Remarkable sunsets began in September.
Manipay, Jaffna ('Ceylon Observer').	Sept. 9.	In the evening, sun blue and so dim as to be easily gazed at. No shadow at 5 p.m. Sky murky red. Deeper blue as sun declined. No halo, clear disc.
Dodanduwa, Ceylon (Mr. Ingleby, 'Ceylon Observer,' September 26).	Sept. 9, 10.	Sun lemon colour, and not much brighter than the moon.
Madras—13° 5′ N. 80° 17′ E. ('Madras Mail').	Sept. 9, 10, 11, 12.	Sun green. Blue by one account. On September 10 sun rose blue, and was blue from 6 to 10 a.m.
Tripatore, Salem District, India—About 13° N. 80° E. ('Ceylon Times').	Sept. 10.	Peculiar white sun in morning, more vividly white than the electric light.
Bellary—15° 10′ N. 76° 40′ E. ('Ceylon Observer').	Sept. 10.	Sun faint green, and rayless on a cloudless sky, like the moon. Crossed by two dull-hued ill-defined belts, not continued, like clouds, beyond the sun's disc.
Calicut—11° 12′ N. 75° 48′ E. ('Ceylon Observer').	Sept. 10.	For three quarters of an hour before setting, sun green. After sunset, for fully 40 minutes, whole western sky lighted up by brilliant red glow, as of a great conflagration.

PLACE.	DATE.	NOTES.
Kurnool ('Ceylon Observer')..	Sept. 10.	From about 4.30 p.m. on September 10, 11, and 12, sun strange steely-blue or slaty-green. Sunset followed by very unusual orange glow, lasting long after the ordinary time. Three days the same.
Kalmunai ('Ceylon Observer')	Sept. 10.	In rising and setting, the sun appeared like the moon. The same appearance continued morning and evening for three days.
Glengoil—922 English miles E. of Galle, to Galle ('Ceylon Observer').	Sept. 9, 10, 11.	Sun blue and dull.
Puliadierakam ('Ceylon Observer').	Sept. 9, 10, 11, 12.	Sun rose splendidly green, turning to blue later. When at about 45° it is too dazzling to look at, but even at midday it is blue, like the moon. Turns green again at setting. Moon looks blue after sunset; and, in declining, gives a fiery light.
Pondicherry ('Times' of Ceylon).	Sept. 10, 11, 12.	Sun dim and blue.
Jaffna, Ceylon ('Ceylon Observer').	Sept. 10, 11, 12.	Sun green and dim. From the 13th sun looked as usual. On September 13 and 14 brilliant red light 7 to 7.15 p.m.
Chittoor (Dr. Ratton, 'Ceylon Observer,' 'Madras Mail').	Sept. 10.	This morning the colour of the sun changed to bluish-green. Remained till 12th. Warm glow lingers in west long after sunset, quite unusual.
Ootacamund (S. S. T., 'Nature,' November 8, 1883).	In Sept.	A green cloud-like mist, and then a reddish mist, passed across the sun.
Trichinopoly ('Nature,' March 6, 1884).	Sept. 10.	From about this date a green sun.
Papa—1° S. 165°·1 W. (MS., Captain Bannau).	Sept. 10.	Sky still veiled with a yellow stratum.
Greyhound—Poochin, 17 miles east of Hoihow, Hainan (MS.).	Sept. 10.	Sun pale green and sky red. Brilliant colours.
Jaffna, Ceylon ('Ceylon Observer').	Sept. 10.	Blue sun. Red light from 7 to 7.15. p.m.
10° 48′ N. 78° 52′ E. ('Ceylon Observer,' October 25).	Sept. 10.	Subdued sun like moon, pearly-green at 15° above horison. Hazy sky.
Scotia—12° 23′ N. 45° 41′ E. (Met. Office Log).	Sept. 10.	8 a.m. Thin cirro-stratus covering whole sky. Moon green before setting.
Ongole, Southern India—15° 30′ N. 80° 6′ E. (Rev. W. R. Manley, 'Nature,' October 11, 1883).	Sept. 9, 10.	Twilight glows first noticed, mottled smoky haze after sunset. On September 11 and 12 splendid glows. Coloured suns. Deep red more than one hour after sunset. Order of colours from horizon, yellow, orange, red.

PLACE.	DATE.	NOTES.
Belfast—18° N. 85° 40′ E. (Met. Office Log).	Sept. 10.	Sun blue, like moon, from 4 p.m., changing for the last 10 minutes before sunset slowly to olive-green, and disappeared about 2° above horizon. At noon light brown clouds like yesterday.
Elopura, north coast of Borneo (Verbeek's Report, p. 147).	Sept. 10 (?)	Green sun.
Scotia, Red Sea (MS. and Met. Office Log).	Sept. 11 and following days.	Sun green at rising and setting on 11th and 12th. Moon green at 20° altitude on September 11, shining through cirro-stratus. The glows were seen as far as 15° N. 42° 30′ E., ship going north. Yellow was the lowest colour, orange intermediate, and red uppermost. At 14° 7′ N. 42° 45′ E. thin cirro-stratus covering the whole sky.
42° S. 44° W. ('Met. Zeitschrift').	Sept. 12, 13.	Splendid sunrises and sunsets.
Schiller—44°·2 S. 46°·8 W. ('Met. Zeitschrift').	Sept. 12.	Splendid sunset. Atmosphere brown and yellow on green background. Long white streaks of cirrus.
Muscat—23° 29′ N. 58° 33′ E. (MS.)	Sept. 12.	Glows began on this day. The maxima were on September 13, 28, and October 12 and 27. They lasted at least two hours after sunset. A white sheen appeared about 10 minutes before sunset. Two hours before sunrise, redness like a conflagration.
Trichinopoly—10° 47′ N. 78° 43′ E. ('Ceylon Observer').	Sept. 12.	Green sun from about this date.
Wisconsin, U.S.A. (S. S. R.) ..	Sept. to March.	Brilliant sunsets seen during this period.
Colombo ('Ceylon Observer,' September 17, 1883).	Sept. 9, 10, 11, 12.	The sun rises a splendid green when visible, *i.e.*, about 10° from the horizon. As he advances he assumes a beautiful blue. . . Then as he declines he assumes the same changes, but *vice versâ*. The moon, now visible in the afternoons, looks also tinged with blue after sunset, and as she declines assumes a very fiery colour 30° from the zenith.
Madras (Prof. M. Smith, 'Nature,' August 7, 1884).	Sept. 12.	Sun set as a greenish-yellow ball, having been green a little earlier.
Madras (Mr. Pogson, 'Nature,' August 7, 1884).	Sept. 12.	At 5 a.m. on September 12 the sky a very remarkably intense reddish-yellow. At 5.10 a.m., sky less red, but bright orange-yellow. Light enough to read by easily. At 5.20, sky pretty clear in east to about 20° altitude, and rich red, rest of sky bright yellow. About 5.26 much less light, and dark red in east, rest of sky greenish-yellow. At 5.40 the low cloud-stratum (in east) sea-green. Much less light to read by. At 5.50, sun rising, bright yellowish-white.

PLACE.	DATE.	NOTES.
Papa—At Sydney Island, 4°·4 S. 170°·5 W. (MS., Captain Bannau).	Sept. 13.	Still a yellow haze in the upper atmosphere, but less dense.
Indian Ocean	Sept. 13.	Green sun.
Scotia—21° N. 38° E. (Met. Office Log).	Sept. 13.	Haze everywhere.
Queen of Cambria—14° N. 26° 42′ W. (Met. Office Log).	Sept. 13.	"I don't know what to call the stuff that is seen in the upper regions, thin cirro-stratus or haze. It was like that seen south of the equator, first, early on September 1, and last on September 5."
Colombo, Ceylon ('Knowledge,' Dec. 14, 1883).	Sept. 13.	"Lately, besides the green sun, the weather has been abnormal; very dense white and leaden coloured clouds."
Jaffna, Ceylon ('Ceylon Observer').	Sept. 13, 14.	Bright-red glows from 7 to 7.15 p.m.
Off Kuria, north of Kingsmill Group, Equator, 172° E. (Mr. F. L. Clarke, in 'Honolulu Advertiser').	Sept. 14.	Most brilliant sunset. Gorgeous hues. Rich crimson with bars of deep blue radiating from west.
Ida—15°·2 S. 87°·3 E. ('Met. Zeitschrift').	Sept. 14.	Half an hour before sunrise intense red glow. Sun rose as a pale greenish-yellow disc. From 6.30 to 7.15 p.m. lurid redness like distant conflagration.
Carola—11°·2 N. 19°·9 W. ('Met. Zeitschrift').	Sept. 14.	The sun at 5° before setting became light-green. Cloud stratum in west, uniform grey.
Queen of Cambria—14° 31′ N. 27° 2′ W. (Met. Office Log).	Sept. 14.	Same sky haze as on 13th. The sun appeared quite green when setting.
Pallai, Ceylon ('Ceylon Observer,' September 20, 1883).	Sept. 14.	The sun seems to have quite recovered his brightness, and all signs of the peculiar green or bluish appearance he presented a few days ago have vanished. For the last evening or two, however, a remarkable lurid glow, as from an immense conflagration, has been noticeable all over the western sky long after sunset.
Colombo, Ceylon ('Ceylon Observer,' September 20).	Sept. 14.	"Neither we nor any who have yet recorded their observations can remember the zodiacal light being coloured green. There was also the persistence of the colouring for three successive days," &c.
Jaffna, Ceylon ('Times of Ceylon,' September 20).	Sept. 13, 14.	At about 7 in the evening, the western part of the horizon was lit up by an unusual brilliant red light. It lasted for about a quarter of an hour, and then gradually disappeared.

Place.	Date.	Notes.
Madras (Mr. Pogson, 'Nature,' August 7, 1884).	Sept. 14.	Sky golden-red till 6.50 p.m.
Madras (Mr. Pogson, 'Nature,' August 7, 1884).	Sept. 15.	In the west the colour was golden to orange-yellow, in the east greenish. Red clouds till 7.5 p.m.
Bhopal, India—23° N. 77° E. ('Nature,' April 24, 1884).	Sept., Oct., Nov., and early Dec.	Very intense after-glows.
South Australia ('Nature,' December 20, 1883).	Sept. 15.	From this date to the end of the month the twilight glows were seen. From September 18 "aurora" after sunset. Duration about 1 hour 35 minutes. Secondary appeared when primary was about 7° or 8° above horizon.
Tasmania—42° S. 146° 45′ E. ('Met. Zeitschrift;' Mercury, Hobart Town).	Sept. 15.	Twilight phenomena first seen.
Carola—14°·8 N. 20°·8 W. ('Met. Zeitschrift').	Sept. 15.	Corona round moon about 15°, red outside.
Frieda Grampp—11°·3 N. 27°·3 W. ('Met. Zeitschrift').	Sept. 15.	Sun grass-green at rising and setting.
Queen of Cambria—About 15° N. 27° W. (Met. Office Log).	Sept. 15.	Same peculiar haze.
Superb—10° N. 146° W. (Met. Office Log).	Sept. 15.	Halo 45° diameter.
Barbadoes—13° N. 59° 30′ W. (Mr. Symons, 'Times' December 5, 1883).	Sept. 15, 16.	Sun various colours.
South-east Australia, Port Augusta to Melbourne (Mr. Todd, 'Nature,' December 20, 1883).	Sept. 16.	From this date twilight phenomena.
Thessalus—28° 29′ S. 81° 45′ E. (Met. Office Log).	Sept. 16.	A remarkably fine sunset sky at 7 p.m., blood-red in west. A red haze round the moon all night.
Frieda Grampp—12°·2 N. 27°·5 W. ('Met. Zeitschrift').	Sept. 16.	Sun and moon of a green tint at rising and setting.
Coppename—42° N. 39° 30′ W. (Met. Office Log).	Sept. 16.	Halo round moon 8 p.m.
Thessalus—27° 49′ S. 82° 23′ E. (Met. Office Log).	Sept. 17.	The sky, half an hour before sunrise, had a singular appearance, assuming a very unnatural and appalling colour.
Superb—About 12° 12′ N. 146° 7′ W. (Mr. Dove, MS.; Captain, Met. Office Log.)	Sept. 17.	Sun like a green ball when rising, and continued so for some time; moon also green. Thin cirro-stratus.

PLACE.	DATE.	NOTES.
Borghese—23° 44′ N., 18° 41′ W. (Met. Office Log).	Sept. 17.	Sky luminous about 6 p.m.
Colombo, Ceylon	Sept. 17.	Magnificent sunset. Warm red colours. Apparently too bright and long-continued to be due to anything short of the zodiacal light. Later the atmosphere looked green.
New South Wales	Sept. 18.	From this date aurora after sunset.
Borghese—19° N. 21° W. (Met. Office Log).	Sept. 18.	Sky luminous about 6 p.m.
Hope—24° N. 140° 5′ W. (Captain Penhallow, 'Nature,' December 20).	Sept. 18.	Fine twilight glows.
Superb—(Mr. Dove, MS.) ..	Sept. 18.	Rose at 6 a.m. to see the green sun, but it had gone behind clouds, through which the green sunlight was visible. Peculiar brass-coloured clouds in west at sunset.
Superb (Captain)—15° N. 147° W. (Met. Office Log).	Sept. 18.	High thin stratus.
Superb—About 19° N. 150° W. (Mr. Dove, MS.)	Sept. 19, 20.	Beautiful sunsets. Long narrow clouds like wrinkles in the sky.
Cape of Good Hope	Sept. 20.	Twilight glows first generally observed.
Graaf Reinet, Transvaal—32° 16′ S. 24° 53′ E. (Mr. Carey Hobson, 'Nature,' November 29, 1883).	About Sept. 20.	Prolonged lurid light 1 hour. Glows began to be noticed.
Jason—49°·9 S. 48° W. ('Met. Zeits.').	Sept. 20.	After sunset strange appearance of the sky in west; all hues of red; in east yellowish-green or blue.
Emma Römer—34°·9 S. 22°·4 E. ('Met. Zeitschrift').	Sept. 20.	Red sky long after sunset.
Chelsea, London—51° 32′ N. (Mr. Ascroft, MS.)	Sept. 20.	After-glow, first undoubted appearance of peculiar glow.
Superb (Captain)—22° N, 150° W. (Met. Office Log).	Sept. 21,	Beautiful parallel streaks of cirro-cumulus on north-western horizon.
Thessalus—13° S. 82° 46′ E. (Met. Office Log).	Sept. 21.	From half an hour past sunset to past 7 o'clock the sky in south-west was red like "aurora borealis."
Coppename—49° N. 20° 16′ W. (Met. Office Log).	Sept. 21.	At 6 a.m. upper sky red, then orange tinged with green.
Umballa—30° 30′ N. 76° 30′ E. ('Met. Zeitschrift').	Sept. 21 to 30.	Splendid glows.
Santiago, Chili ('Met. Zeitschrift').	Sept. 21 to 30, and previously.	Twilight glows.

PLACE.	DATE.	NOTES.
North Pacific (Mr. Bishop) ..	Before Sept. 22.	Traders to Honolulu had noticed the haze, &c., a considerable time before September 22.
Madras (Mr. Pogson, 'Nature,' August 7, 1884).	Sept. 22.	Sun rose as a yellow ball, and showed distinct greenish-yellow afterwards.
Lunugala, Ceylon ('Ceylon Observer').	Sept. 22.	Sun like moon at 7 a.m.
Colombo ('Ceylon Observer')..	Sept. 22.	Green sun returned evening of 22nd.
Ceylon (Ceylon newspapers) ..	Sept. 22.	Green sun returned. At Jaffna first seen again on 21st.
Mannâr, Ceylon ('Ceylon Observer').	Sept. 22.	Sun pale green in the evening.
10° 48′ N. 78° 52′ E. (A. T. F., 'Ceylon Observer,' October 25).	Sept. 22.	Sun's disk of a hue in which green predominated.
Hawaii (Rev. S. E. Bishop) ..	Sept. 22.	Renewal of glows.
Madras (Mr. Pogson, 'Nature,' August 7, 1884).	Sept. 23.	Sun rose very green.
Colombo ('Ceylon Observer')..	Sept. 23.	At 2 a.m. moon dull and green coloured. Sun rose dull and rayless, with a tinge of green.
Mannâr, Ceylon ('Ceylon Observer').	Sept. 23.	Sun pale green on rising. In setting left only a greenish instead of golden light in the sky.
Lyttelton—31° S. 39° 55′ W. (Met. Office Log).	Sept. 23.	Sky has a peculiar fiery appearance, as of a large fire behind the bank of clouds.
Superb—26° 29′ N. 147° 52′ W. (Met. Office Log).	Sept. 24.	Cirro-cumulus arranged in lines from S.S.W.½-W. to N.N.E.½-E.; a perfect cirro-cumulus.
Ceylon (Mr. H. Parker, MS.)..	Sept. 24.	Green appearance in sky similar to that of September 9 and 10, but not so vivid; sun's disc defined, and greenish-yellow; sky around it yellowish-green. Sky hazy. Just after sunset leaden-blue till half an hour after; orange in west. Broad distinct palish streaks pointing west.
Thessalus—4° S. 83° 9′ E. (Met. Office Log).	Sept. 24.	Yellow sky to east at 8 a.m.
Duem—14° N. 32° 30′ E. (Hicks Pasha, 'Times,' December 14).	Sept. 24.	Sun rose green.
Ireland ('Met. Zeitschrift') ..	Sept. 24 and following days.	First appearance of after-glows.
Réunion—21° S. 55° 30′ E. ..	Sept. 25.	From this date continuously magnificent glows.

PLACE.	DATE.	NOTES.
Saghalie—K. George's Sound to north of Bourbon (Flammarion).	Sept. 25 to Oct. 12.	Remarkable sunsets.
Scotia—36° N. 4° W. (Met. Office Log).	Sept. 26.	8 a.m., hazy round horizon. Zodiacal light at 7.26 p.m.
Haslemere, Surrey (Hon. R. Russell, MS.)	Sept. 26, 27.	Light pink cirrus stripes at sunset.
Ceylon ('Times' of Ceylon, September 28, 1883).	Sept. 27.	"Yesterday morning, when the sun rose a little above the horizon, it looked very beautiful, being of a soft greenish tint, and as it set, instead of the golden streaks it leaves behind, we saw only a sort of greenish light. It still continues the same."
Ida—27°·9 S. 46°·3 E. ('Met. Zeitschrift').	Sept. 27.	Sky exactly as on September 14 (see p. 285).
Kurrachee (Mr. F. C. Constable, 'Nature,' November 15, 1883).	Sept. 28.	From this date red glow after sunset, greenish sky and green moon.
Olbers—9° S. 35° W. (Met. Office Log).	Sept. 28.	Sun set pale blue.
H.M.S. *Magpie*, Labuan, Captain Vereker (Met. Office Log).	Sept. 29.	A yellow coloured fine-looking sky at sunset.
Olbers—5° 13′ S. 35° W. (Met. Office Log).	Sept. 29.	Sun whitish appearance 5.30 p.m.
Olbers—2° S. 38° W. (Met. Office Log).	Sept. 30.	Sunset bright amber.
Brazil, locality not stated ..	Sept. 30.	Red sunsets began.
Rio de Janeiro (M. Cruls, 'Comptes Rendus,' April 21, 1884).	End of Sept.	The glows began about this time, but the glow then was of short duration, and the sun set rayless in a misty stratum.
Arequipa ('Met. Zeitschrift')..	Last days of Sept.	Very strong glows, as never before seen.
Buenos Ayres (M. Beuf, 'Comptes Rendus,' February 25, 1884).	Last days of Sept.	The glows began. They lasted 1 hr. 30 min. The sun and moon were occasionally coloured.
Somerset, Mass. U.S. (S. S. R.)	Sept. and Oct.	Beautiful sunsets.
Olbers—1° 23′ N. 41° 5′ W. (Met. Office Log).	Oct. 1.	Sunrise very pale.
Foochow (Father Dechevrens, &c.).	Early in Oct.	Fiery skies. Taken at first for a conflagration.
Shanghai—31° 14′ N. 121° 27′ E. (Father Dechevrens, 'N. China Daily News').	Beginning of Oct.	Fiery skies. From first days of October to December 16th intense red in western sky.

Place.	Date.	Notes.
Orissa—18° 17′ N. 86° 44′ E. (Met. Office Log).	Oct. 2.	Red glare or halo round sun at noon, 25° to 30° diameter.
Honolulu (Rev. S. E. Bishop, 'Nature,' April 10, 1884).	October.	Glow continued remarkable, but extremely unequal.
Bhopal, India—23° 30′ N. 77° 30′ E. ('Nature,' April 24, 1884).	October.	Fine glows continued. Observed in September, October, November, and part of December. Partial return in March.
Jason—25°·7 S. 29°·5 W. ('Met. Zeitschrift').	Oct. 2.	Strong glow to 1 hour after sunset.
Arabia	Oct. 1 to 14.	Remarkable glows.
Mauritius (Dr. Meldrum, 'Proc. Met. Soc. of Mauritius,' &c.)	During October.	Prolonged and intense glows lasting 1 hour 15 minutes. At Réunion magnificent glows.
Canary Isles—28° 30′ N. 16° W.	Oct. 1 to 10.	Glows.
Gulf of Mexico	Throughout Oct.	Splendid glows.
Yucatan (Met. 'Zeitschrift,' March, 1884).	All through Oct.	Twilight phenomena continued.
Haslemere, Surrey (Hon. R. Russell).	Oct. 3.	Red and yellow sunset.
St. Kilda—29° N. 27° W. (Met. Office Log)	Oct. 4.	At 8 a.m., sky covered with cirro-stratus; sky aloft pale yellow at 6 p.m.; new moon quite green.
Jason—24°·3 S. 29°·1 W. ('Met. Zeitschrift').	Oct. 4.	Strong glow to 7.30 p.m.
Thessalus—13° 30′ N. 89° 11′ E. (Met. Office Log).	Oct. 4.	Sky yellow near sun.
Virginia, U.S.A. (S. S. R.). ..	Oct. 5, and later.	Fine glows.
Somerset, Mass., U.S.A. ('Met. Zeitschrift,' March, 1884).	Oct. 5, and later.	Magnificent and frequent glows.
Carrizal Bay (about 300 English miles N. of Valparaiso)—29° S. 72° W.	Oct. 5.	Red sunsets began.
Nashville, Tennessee, U.S.A. (S. S. R.).	Oct. 7.	Sunset shadows very bright.
Buenos Ayres and Monte Video —34° 39′ S. 58° 23′ W. ('Met. Zeitschrift').	Oct. 7, 8.	Very vivid sunsets.
St. Kilda—23° 25′, N. 33° 15′ W. (Met. Office Log).	Oct. 7.	At 7 a.m., clouds above and below the sun of the colour of fire rust (*sic*), the sides of the sun quite white.

PLACE.	DATE.	NOTES.
St. Kilda—23° N. 34° W. (Met. Office Log).	Oct. 8.	Sky as on 7th.
Pensacola, Florida ('Met. Zeitschrift;' S. S. R.).	Oct. 8, 9.	First red twilights, sunrise and sunset. Magnificent. Red up to zenith, appearance of a vast fire.
Binninag, 40 English miles from Almorah—29° 30′ N. 80° E. (MS.).	Oct. 8, 9.	Red and fiery after-glow till 7.20 p.m.
Glencairn—14° S. 84° E. (Met. Office Log).	Oct. 8.	Very peculiar appearance of the sky in the S.W.; like reflection of a large conflagration, 34° south of sunset at 7 p.m.
Thessalus—18° N. 90° 50′ E. (Met. Office Log).	Oct. 9.	Sky very yellow near sun; at 6.30 p.m., sky in W.N.W. soft fine red.
Hankow, China (Mr. MacGowan, 'Knowledge,' March 21, 1884)	Oct. 9.	After-glows began about this time.
Swatow—23° N. 117° E. (MS. from Lighthouse).	Early in Oct.	Brilliant glow about three quarters of an hour.
Hobart, Tasmania	Early in Oct.	Magnificent sunsets. October 12 fine after-glow.
Cape of Good Hope—34° S. 18° 30′ E. ('Met. Zeitschrift').	October.	Magnificent glows continued.
China Seas (MS.)	October and November.	Glows observed by pilots.
St. Kilda—About 20° N. 37° W. (Met. Office Log).	Oct. 10.	Sky as on 7th.
Schiller—9°·5 S. 24°·3 W. ('Met. Zeitschrift').	Oct. 10.	Cloudless sky, fiery air.
Schiller—6°·9 S. 24°·1 W. ..	Oct. 11, 12.	Cloudless sky, fiery air.
Perth, W. Australia ('Met. Zeitschrift').	Oct. 11 to 20.	Twilight glows.
Hambantota, Ceylon (Mr. Parker, MS.)	Oct. 11.	Haziness still remaining, and greenish sky.
Sunbeam—Near Canary Islands (Lady Brassey, 'The Roaring Forties').	Oct. 11.	Indescribably splendid sunset. Sky coloured purple, orange, yellow, green, and blue.
Kurrachee ('Knowledge,' November 23, 1883).	Oct. 14.	Brilliant glow after sunset.
Santa Barbara, California—34° 27′ N. 119° 50′ W. (Rev. S. E. Bishop, MS., &c.)	Oct. 14.	Fine after-glow.

Place.	Date.	Notes.
Orissa—11° 37′ N. 82° 57′ E. (Met. Office Log).	Oct. 14.	From 8 p.m. to midnight, circle round moon 45° in diameter.
Montgomery, Alabama, U.S.A. —32° 21′ N. 86 23′ W. ('Met. Zeitschrift').	Oct. 15.	Vivid after-glow. On October 14 very peculiar appearance in western sky.
Drenthe—18° 36′ N. 39° 44′ E. (Ship's Log).	Oct. 15.	Remarkable yellowish sky after sunset.
Nice—43° 42′ N. 7° 16′ E. ('Knowledge,' December 7, 1883).	About Oct. 15.	Extraordinarily beautiful sunsets and long glow.
Lisbon—38° 41′ N. 9° 10′ W. (Captain de B. Capello, Observatory, 'Standard,' and MS.)	Oct. 15 to 24.	Remarkable sunsets with after-glows. Maximum October 18. White apparent cirrus or cirro-stratus visible after sunset.
Teneriffe—28° 25′ N. 16° 40′ W. ('Times').	About Oct.	Glows lasted 1 hour. Sunrise light like fire.
Orissa—8° 42′ N. 82° 50′ E. (Met. Office Log).	Oct. 16.	At sunrise ugly looking sky, brick-red under sun to 20° altitude.
Glencairn—13° 34′ S. 91° 32′ E. (Met. Office Log).	Oct. 17.	Very broad dark-reddish or copper colour ring round moon.
Oakwood, San Diego Co., California (S. S. R.).	Oct. 19.	First twilight phenomena. On October 18 white ring round sun.
Yuma—About 33° N. 115° W. (Signal Service Report).	Oct. 19 and 20.	Sky beautifully red 1½ hours after sunset.
Batavia	Oct. 20.	Fiery light in west.
Port Elizabeth, Natal (MS.) ..	Before and on Oct. 20.	Heavens aflame nightly.
Mhow, Kurrachee—24° N. 68° E. (MS.)	Before and on Oct. 20.	Very brilliant glows, chiefly greenish.
Chelsea, London (Mr. Ascroft, MS.).	Oct. 20.	After-glow prolonged.
Haslemere, Surrey (Hon. R. Russell).	Oct. 20.	Fine reddish sunset, with bright isolated cloud, and slight low cirrus. High cirro-stratus or something similar.
Umballa—30° 30′ N. 76° 30′ E. ('Nature,' December 13, 1883).	Some time before Oct. 20.	Fine glows.
Santiago, Chili ('Met. Zeitschrift').	Oct. 21 to 31.	Twilight glows continued.
Haslemere, Surrey (Hon. R. Russell's Register).	Oct. 21.	Fine reddish and orange sunset.

PLACE.	DATE.	NOTES.
Yuma, Arizona, U.S.A.—About 32° 45′ N. 114° 38′ W. (S. S. R.).	Oct. 21.	Blood-red sky till 1½ hour after sunset.
Haslemere, Surrey (Hon. R. Russell's Register).	Oct. 22.	Sun set in "bath" of cirrus. Halo effect, red; rest of sky clear.
Haslemere, Surrey (Hon. R. Russell's Register).	Oct. 23.	Sun set in clear sky, but white mistiness on horizon.
Santos, Brazil (The Consul, MS.)	From about Oct. 22.	Glows.
Fort Grant, Arizona (S. S. R.).	Oct. 23.	Magnificent and peculiar sunset.
Kangra Valley—32° N. 76° E. .	Oct. 24.	Curious glow like aurora long after sunset.
Kuasin—Woosung, China (Captain Anderson, MS.)	Oct. 26.	Most extraordinary sunset. Sun set white and without power in the midst of an arch of intense red. The red arch reached to 30° or 35°. Similar sunsets October 31 and November 2 and 7.
Iquique—20° 10′ S. 70° 7′ W. ('Met. Zeitschrift').	Oct. 25.	Sunset 6.15.; splendid glow till 7.20 p.m.
Shanghai—31° 14′ N. 121° 27′ E. (MS.)	Oct. 26.	White sun, red arch, various hues, milky-white stratum. Appearance of a raging fire.
Orontes—Just south of Equator, off W. African coast (Lieut. Hope, 'Nature,' December 13, 1883).	Oct. 25.	Splendid glow in S.W., red till 8 p.m.
Lanzarote, Canary Islands—About 29° N. 14° W. (Mr. Buchanan, 'Times,' December 25).	Oct. 27.	Splendid glows.
Haslemere, Surrey (Hon. R. Russell's Register).	Oct. 27.	Some streaks of soft delicate cirrus in irregular patches, turning fine pink at sunset. Glow from horizon.
Mauritius (Dr. Meldrum, MS. and 'Proc. Met. Soc. of Mauritius').	Aug. 28 to Oct. 27.	Extraordinary sunsets.
Wellington, Kansas ('Met. Zeitschrift').	Oct. 28.	Bright red sunset.
Nashville (Tenn.) (S. S. R.) ..	Oct. 29.	Magnificent sunset. Red till 6.40.
San Diego, California (S. S. R.).	Oct. 30.	Brilliant reflection in western sky.
Eastern States of N. America (Signal Service Report).	Oct. 30.	Fine sunsets began.
Nashville (Tenn.), Atlanta (Georgia), Charlotte (N. Carolina), Lynchburg (Virginia), Memphis (Tenn.) (S. S. R.).	Oct. 30.	Beautiful sunset. "Like a vast fire" at Charlotte. Lasting more than 1 hour at Memphis.

PLACE.	DATE.	NOTES.
Kamptee, Madras ('Knowledge,' November 30, 1883).	Oct. 30.	The extraordinary glows have continued, nearly every evening. After the sky got dark, it gradually re-assumed the most brilliant roseate hues. Also sun used to be green in the morning.
Memphis, Tennessee, U.S. (Signal Service Report).	Oct. 29, 30, 31.	Glows.
Atlanta (Georgia), Stateburg (S. Carolina), Lynchburg (Virginia), (S. S. R.).	Oct. 30, 31.	Brilliant red sunsets. At Lynchburg rosy glow up to 45° from horizon, like zodiacal light.
Santos, Brazil (Consul, MS.) ..	End of Oct.	Glows. Red glare.
Belfast—31° 21′ S. 13° 15′ E. (Met. Office Log).	Oct. 31.	Zodiacal light till 9 p.m.
Roscommon, Ireland (A. C., 'Nature,' February 21, 1884).	End of Oct.	Glows after sunset. All phenomena as observed by Prof. Divers in Japan.
Honolulu (Rev. S. E. Bishop, 'Nature,' April 10, 1884).	Nov.	Great abatement of the glows during this month.
Sydney, N.S.W. (Mr. Hargrave, MS.)	Nov. 1.	Sunset 6.25. First phase 6.40. Deep crimson near horizon 7.10. Streaky white above crimson. Second glow began 7.12. Pink nearly gone 7.45.
Kailong, Lahoul — About 32° 40′ N. 77° E. (MS.)	Nov. 1.	Sheen round sun about 80° diameter. Glows began. Sun could be looked at at midday.
Roy. Observatory, Greenwich ('Standard,' December 26, 1883).	Nov. 2.	Brilliant sunset.
Somerset, Bristol Co., U.S. ('Zeits. für Met.').	Nov. 3.	Splendid glows. Also on 11th, 13th, 25th, and 27th.
Rosario—2° to 13° S. 33° to 36° W. ('Met. Zeitschrift').	Nov. 5 to 8.	Hazy air.
Vester Torslev, Denmark (MS.)	Nov. 5 to 12.	First glow observed.
Sunbeam—Gulf of Paria, Venezuela (Lady Brassey, 'Roaring Forties').	Nov. 4.	Sunrise marvellously fine.
Haslemere, Surrey (Hon. R. Russell's Register).	Nov. 8.	"Fine sunset with straight lines of cirrus (?) and very slight bank. Long after sunset and till nearly dark a pink glow from some very high filmy cirrus."
Maresfield, Sussex ('Knowledge,' November 30, Captain Noble).	Nov. 8.	Glow observed.
Greenwich ('Nature,' January 31, 1884, Mr. Ellis).	Nov. 8, 9, &c.	Glows.

PLACE.	DATE.	NOTES.
Forsyth, Monroe Co., Georgia, U.S. (Signal Service Report).	Nov.	Throughout the month beautiful sky before and after sunset. Like aurora on 29th.
On the Volga ('Met. Zeitschrift').	About Nov. 8.	Glow seen.
Nelson Co., Virginia, U.S. (Signal Service Report).	Nov.	Glow nearly every fair day during the month. Max. 27th and 28th.
Haslemere, Surrey (Hon. R. Russell's Register).	Nov. 9.	At 8 a.m. detached cirrus, cirro-cumulus, and cirro-stratus moving fast from W.S.W. At 9 a.m., series of rippled cirrus in web-like uncrossed striæ moving transversely. At 7.30 a.m. some high pink filmy cirrus (?) like last night. At 11.20 a.m. blue sky, but some large patches of very high cirro-cumulus, one overhead in very small fleeces and partly in re-curved waves or bars. Light of the sun in setting peculiarly yellow, with slight bank of haze. Sky clear and blue. At 15 minutes after sunset extraordinary red, green, yellow, and white opalescence. Very strong red glow, lasting 1 hour and 40 minutes after sunset, from an apparently motionless film.
Sudbury, Suffolk (Dr. H. Airy in 'Nature,' November 29, 1883).	Nov. 9.	Glow seen.
Cape of Good Hope ('Met. Zeitschrift').	From Nov. 9.	Glows continued fine.
Laconia, Harrison Co., Indiana (Signal Service Report).	Nov. 9 to 30.	Very brilliant sunrises and sunsets.
Sussex, Kent, Suffolk, Middlesex, Worcester, Isle of Wight, Oxfordshire ('Daily Chronicle,' November 10).	Nov. 9.	Strong and long-continued red glow after sunset Described as "aurora" at Dover, and "very like aurora" at Oxford. At Worcester, like "a great conflagration."
Babbacombe, Devonshire (Mr. Glyde).	Nov. 9.	Very fine rosy glow after sunset.
Haslemere, Surrey (Hon. R. Russell's Register).	Nov. 10.	At 6.20 a.m. pink sunrise light in the east. About 3.30 p.m., on close scrutiny of the clear sky, a very thin high rippled haze visible in parts. About 4.32, 14 minutes after sunset, a small portion in the west began to glow, and lasted bright pink till 5.10.
Minnesota, New Garden, N. Carolina, and other places in the U.S. ('Met. Zeitschrift').	Nov. 10.	Splendid sunset.
Bertha—45°·5 N. 24°·2 W. ('Met. Zeitschrift').	Nov. 10.	Light red mist in west about sunset.
Dublin	Nov. 11.	Sky brilliant with cirrus.

PLACE.	DATE.	NOTES.
Simbirsk—54° N. 48° E. ('Met. Zeitschrift').	Nov. 11.	Fine glows.
Amarapoora—10° 16′ N. 86° 34′ E. (Met. Office Log).	Nov. 12.	Very peculiar appearance in sky, as if the upper cirrus full of fine yellow sand, night and day.
Switzerland (Professor Forel, 'Comptes Rendus').	Nov. 11 to 21.	Corona round sun between these dates.
Leipzig—23° N. 18°·8 W. ('Met. Zeitschrift').	Nov. 12, 13.	Strong after-glow.
Royal Observatory, Greenwich	Nov. 13.	Clouds in N.W. tinged with crimson from 3 p.m. to sunset.
Salina, Kansas—38° N. 97° W. ('Met. Zeitschrift').	Nov. 14.	Glows first seen.
Florida (S. S. R.)	Nov. 15.	Glows began again.
Louisville—38° 15′ N. 86° W. (Signal Service Report).	Nov. 15.	Glow first seen.
Wellington, Sumner Co., Kansas (Signal Service Report).	Nov. 15 to 30.	Before sunrise a red or orange band, then yellow, and afterwards green zone.
Louisville, Kentucky (S. S. R.).	Nov. 15 to 30.	Glows.
Carson, Armstrong Co., Nevada (Signal Service Report).	Nov. 18 to 30.	Glows.
Berkeley, California (Prof. J. Le Conte, 'Nature,' February 28, 1884).	Middle of Nov.	First glows. Striking on November 24, when at 6 p.m. the sky had the appearance of a conflagration. Glare round sun.
Hankow, China ('Nature,' March 6, 1884).	Nov. 17.	Green sun and after-glows.
Redhill, Surrey (MS.)	Nov. 16.	Glow after sunset.
Tweedsdale—10°·8 N. 86°·3 E...	Nov. 16, 17.	Sky all day near sun has a peculiar reddish tint. Moon the same on 13th and 14th.
Malaga, Spain	Middle of Nov.	Glows splendid from this time.
Haslemere, Surrey (Hon. R. Russell).	Nov. 17, 18.	Fine sunrise. Deep red and bright yellow.
Flateyrr, extreme N.W. of Iceland (MS.)	Nov. 17.	Colour of clouds brown-red. Fine sunset. On November 18 clouds brown.
Nevada—37° N. 117° W. ('Met. Zeitschrift').	Nov. 18.	Glow first seen; continued till 30th.
Provence, France (M. Gasparin, 'Comptes Rendus,' February 21, 1884).	Nov. 19.	Fine after-glows from this date to January 24, 1884.

PLACE.	DATE.	NOTES.
Colorado College (Prof. G. H. Stone, 'Nature,' February 28, 1884).	Nov.	Soon after middle of November glows and corona.
Auburn, Lee Co., Alabama (Signal Service Report).	Nov. 20 to 27.	The week has been characterised by wonderfully brilliant sunsets.
Haslemere, Surrey (Hon. R. Russell).	Nov. 19.	Fine sunrise. Deep red turning to yellow. White mist.
Toronto (MS. and printed Report).	Nov. 20.	Glows began. Splendid November 22.
Constantinople (Dr. Budde, 'Nature,' December 20, 1883).	Nov. 20.	Glow first seen.
Tambow, Russia (MS.). ..	Nov. 20, 21.	Glow first seen.
Baltimore, U.S. (Mr. W. Numsen, 'Knowledge,' January 4, 1884).	About Nov. 20.	Appearance of a tremendous fire along the horizon, and to an altitude of 40°. Disappeared a little before 7 p.m.
Prague (Brauner, 'Nature,' January 3, 1884).	Nov. 22.	Sunset 4.30. Glow as of a great fire at 5; disappeared about 5.30 p.m.
Castasegna, Switzerland ('Met. Zeitschrift').	Nov. 22.	Strong morning glow.
London, Canada (MS. Report)	Nov. 22.	Most extraordinary sunset. Pitch dark in E. and zenith, a blaze of red lurid fire in W.
Upsala (Hildebrandsson, 'Standard,' December 26, 1883).	Nov. 22.	Splendid rosy tint over western sky, and yellowish-green in N.E. and N. Duration 2 hours.
Nedanocz, Neutra-thal, Hungary ('Zeitschrift für Met.').	Nov. 22.	Very bright glow at 6 a.m.; supposed to be a great fire.
Oregon ('Met. Zeitschrift') ..	Nov. 23 to 30.	Fine twilight glows. Began at 5 a.m. In evening lasted till 6.45 p.m.
Missouri, U.S. ('Met. Zeitschrift').	Nov. 23.	Glows observed generally. At St. Louis, 2 hours before sunrise and after sunset, sky red from horizon to beyond zenith.
Canada (MS., &c.)	Nov. 23.	Earliest glows in many places.
L'Original, Canada	Nov. 23.	Glows. Sunset very red.
Victoria, British Columbia (Rev. — Jenns, MS.).	Nov. 23.	Most magnificent glows this day, as if country ablaze with flame. Their duration was 2 hours.
New Westminster, British Columbia (Captain Peele, MS.)	Nov. 23.	Glows seen. Sun set in cloudless bright-yellow sky. After a few minutes red and yellow arch. Maximum 1½ hour after sunset. Duration about 2 hours. Second glow passed the zenith 1½ hour after sunset.

PLACE.	DATE.	NOTES.
Alabama, California, Humboldt Co. Colorado, Connecticut, Dakota, Florida, Georgia, Illinois, Indiana, Iowa, Delaware, Kansas, Kentucky, Maine, Massachusetts, Michigan, Missouri, Nebraska, Nevada, New Hampshire, New York, N. Carolina, Ohio, Pennsylvania, Texas, Virginia, Washington, Wisconsin, Mississippi (S. S. R.).	Nov. 23, 24.	From this date morning and evening glows. They began in the Northern States about November 21, and were brightest on November 27, 28, and 29.
San Francisco (Rev. S. E. Bishop, 'Nature,' January 17, 1884).	Nov. 23, 24.	Glows first seen.
Reykjavik, Iceland (M. Tromholdt, 'Nature,' February 28, 1884).	Nov. 23.	Purple sky between 5 and 6 p.m.
Bamberg, Germany ('Met. Zeitschrift').	Nov. 23.	Morning glow.
Richmond, Surrey (Hon. R. Russell).	Nov. 23, 24.	On 23rd sun set in cirro-stratus or cirrus-striæ. On 24th sun set in misty striæ, turning yellowish-green after sunset. Sun disappeared several degrees above horizon.
Gravenhurst—44° N. 79° W. ..	Nov. 24.	Glow seen. Brilliant crimson in sky at sunrise and sunset.
Flateyrr, N.W. Iceland (MS.)..	Nov. 24.	At 9.30 a.m. violet sky. Yellow and green clouds.
York and Sunderland (Mr. J. E. Clark, 'Nature,' December 6; Mr. T. W. Backhouse, 'Nature,' January 10, and MS.).	Nov. 24.	First fine sunset. Pink circle round sun distinctly seen November 26.
Bray, Wicklow ('Nature,' December 13, 1883).	Nov. 24.	First glow.
Berkeley, California (Prof. J. Le Conte, 'Nature,' February 28, 1884).	Nov. 24.	Striking after-glow. At 6 p.m. appearance of a great fire. Glare round sun.
Sunbeam—30° 3′ N. 77° 28′ W. (Lady Brassey, 'Roaring Forties').	Nov. 24.	Most splendid sunset. Orange and scarlet after-glow, like aurora, over the sky.
Tatoosh Island, Washington Territory (Signal Service Report).	Nov. 24.	Glow 2 hours after sunset.
St. George's, Delaware, U.S. (Signal Service Report).	Nov. 24.	Glows began and lasted through December.
Monticelli, Jones Co., U.S. (Signal Service Report).	Nov. and Dec.	Glows.

PLACE.	DATE.	NOTES.
Oakwood, San Diego Co., California (Signal Service Report).	Nov. 24.	Sun surrounded by whitish glare during day. Sunset displays from November 24 to 30 as on October 18.
Hydesville, Humboldt Co., California (Signal Service Report).	Nov. 24 to 30.	Very brilliant twilights, morning and evening. Sky became red about 1 or 1½ hour before sunrise, and gradually faded. Just after sunset the sky began to grow red and continued increasing in brilliancy for about 1 hour. On 24th like a great fire in south.
Oakland, Alameda Co., California (Signal Service Report).	Nov. 25.	In the morning a luminous silvery twilight; as the sun came up the light rose nearer to the zenith, changing to a reddish-pink and forming a crescent, beneath which was a pale green colour of an apparent diameter of 60°. As sun rose the colour changed to yellowish-red. Most remarkable display after sunset. Continued the following days.
Lindsay, Canada—44° N. 78° W. (MS. Report).	Nov. 25 (about).	First glow. A very peculiar reddish or brown light in E. before sunrise and in S.W. after sunset.
Hamilton—43° N., 80° W. (MS. Report).	Nov. 25, 26.	Extraordinary sunsets.
Beatrice—45° 8′ N. 79° 20′ W. (MS. Report).	End of Nov.	Haze of a tawny or russet hue, and light of a bluish ghastly character.
Honolulu..	Nov. 25.	Great increase in brilliancy of glows. Mr. Bishop states the glows were renewed early in December, and remained for six weeks as brilliant as in October.
Lisbon, Portugal (Captain De B. Capello, MS. and 'Standard').	Nov. 25.	Glows returned. Duration 1 h. 30 m. to 2 hrs.
Luneville, France	Nov. 25 to Dec. 2.	Morning and evening glows.
Naples (Padre Denza, 'Nature,' Dec. 20, 1883).	Nov. 25.	Sunsets began. Taken for aurora by many.
Italy, Alps to Calabria (Padre Denza, 'Met. Zeitschrift').	Nov. 25 to Dec. 1.	Glow phenomena first seen.
Ashby Parva, Lutterworth (Miss Annie Ley, 'Nature,' Nov. 29, 1883).	Nov. 25.	At 3 p.m., sun white, like electric light, with broad corona about 22° radius. Glow till about 5.45 p.m.
Dover ('Daily Chronicle,' Nov. 26).	Nov. 25.	Fine "aurora."
Royston, Herts (Rev. C. Miles, MS.)	Nov. 25.	Displays began. On November 26 lasted till 5.30; on a later day till 5.45 p.m.
Lichfield; Saltburn; Hunstanton; Skegness ('Standard').	Nov. 25.	Glows seen. At Lichfield, whole sky deep crimson on 26th.
Lichfield (Mrs. Chawner, MS.)	Nov. 25 and 29.	Sky blood-red; most remarkable effects.

PLACE.	DATE.	NOTES.
St. Andrews, Scotland (Mr. J. Dundas, MS.)	Nov. 25.	First display. Finest November 26 and 30.
Montrose, Scotland ('Knowledge,' December 21).	Nov. 25.	Sky filled with deep red colour after sunset, like very bright aurora. Max. November 30, when sky was green, orange, and red. None December 4 to 9.
Dublin	Nov. 25.	Remarkable play of colours after sunset.
Huntingdon, Canada—45° N. 74° W. (MS.).	Nov. 26.	Sky red one hour after sunset.
Dorset, Vermont, U.S. (J. E. Clark, 'Nature,' Jan. 3, 1884).	Nov. 26.	From about this date sky coloured intensely red as by a great fire.
Hee and Aalyke, Denmark—55° 30′ N. 8° 52′ E. (MS.)	Nov. 26.	First glow. From after sunset to 5.30.
France ('Comptes Rendus,' December 10, 1883.)	Nov. 26.	Glows first generally seen. Remarked at Paris, Nice, and Cannes; and eight following days at Cannes, very intense.
Cheltenham (Mr. C. Roly, MS.)	Nov. 26.	Whole sky suffused with deep crimson of great intensity.
Meltham (Mr. C. L. Brook, MS.)	Nov. 26.	Glow round sun at 1 p.m. On following days fiery sunset glow. On 29th, to 5.30 p.m. On 28th clouds overhead greenish-yellow.
Torquay, Devon (Mr. Glyde) ..	Nov. 26.	Glow very fine. Finest, November 9 and 26. Peculiar greyish haze, higher than the highest cirrus.
Ross, Hereford (Mr. Southall, 'Standard,' December 26).	Nov. 26.	Finest glow on this day.
Croydon ('Standard,' see 'Nature,' December 6).	Nov. 26.	Red sky at 3.30 p.m.
Lyons, France ('Comptes Rendus,' December 24, 1883).	Nov. 26.	Glows began on this day. Very light cirri, in long and parallel filaments, were almost always observed.
Whiteside Co., Illinois; Springfield, Illinois; Humboldt, Iowa; Ohio; Johnson Co., Texas; Waukesha, Wisconsin (Signal Service Report).	Nov. 26,	Glows began, in full splendour.
Sumter Co., Georgia; Perry Co., Illinois; Switzerland Co., Indiana; Rush Co., Indiana; Des Moines, Iowa; York Co., Maine; Cumberland Co., Maryland; Bristol Co., Massachusetts; Kent Co., Michigan; Omaha, Nebraska; Galveston; Lexington, Oregon (S. S. R.).	Nov. 27.	Glows began, in full splendour.

PLACE.	DATE.	NOTES.
Centreville, Wisconsin (Signal Service Report).	Nov. 27.	At 7.30 p.m. whole southern horizon bright crimson, centre apparently where sun sets; glow extending from W. to S.E.
Buitenzorg and Serang, Java ..	Last week of Nov. and beginning of Dec.	After-glows very conspicuous.
Scutari, Asia Minor (Mr. W. H. Lyne,'Met. Register,' extract, MS.)	End of Nov.	"A remarkably deep red colour of the sky, clouds, and atmosphere has been noticed at sunrise and sunset on the last three or four days of the month; giving to the sea, earth, buildings, &c., a very peculiar ruddy, hazy, and weird-like appearance."
Southampton ('St. James' Gazette').	Nov. 26.	Very fine after-glow. Light very strong till after 5, when east sky was of a strange green. Second glow till 5.45.
Oxford ('Daily Chronicle') ..	Nov. 26.	Fine "aurora" after sunset.
Ashby Parva, Lutterworth, Miss Annie Ley ('Nature,' Nov. 29th).	Nov. 26.	Altitude of red arc at 5.5 p.m., 25°.
Richmond, Surrey ('Nature')..	Nov. 26.	Sunset phenomena like yesterday, but much stronger. Bright red.
Cirencester ('Nature,' December 6, 1883).	Nov. 26.	Magnificent display, nearly an hour.
London	Nov. 26.	Peculiar glow round sun at 1 p.m.
Nottingham	Nov. 26.	First glow vanished at 4.50.
Glückstadt (Herr Gerber, 'Met. Zeitschrift').	Nov. 26.	Bright red long-continued glow.
Meran—46° 41′ N. 11° 8′ E. ('Met. Zeitschrift').	Nov. 26.	Glows. Brighter glow on 28th.
Brixen; Rügenwalde; Neufahrwasser ('Met. Zeitschrift').	Nov. 26.	First glow. Compared to aurora borealis and reflection of a fire.
Vilsen, Hanover ('Met. Zeitschrift').	Nov. 26.	Glows from this date lasted till 5.45 p.m. On Dec. 5th corona round moon. Sky never pure.
Keitum auf Sylt, Denmark ('Met. Zeitschrift').	Nov. 26.	Marvellous glow.
Paris ('Times,' December 5) ..	Nov. 27.	Brilliant after-glow. Also very fine on 29th and December 2.
Victoria, British Columbia ('Nature,' January 3, 1884).	Nov. 27.	First glows. Long after sunset crimson sky and rays like aurora.
Glückstadt ('Met. Zeitschrift').	Nov. 27.	Bright red glow, as of a great fire, lasting till about 5.40 p.m.

PLACE.	DATE.	NOTES.
Belfast—14° 25′ N. 32° 7′ W. (Met. Office Log).	Nov. 27.	Zodiacal light very plain.
Wooster, Ohio (Prof. Stoddard, 'Nature,' February 17, 1884).	Nov. 27.	Glow very grand. On the days of the bright sunset colouring, there was a sheen of 6° to 8° round the sun.
S. E. Iceland (MS.)	Nov. 27.	Fine sunsets.
Southern Sweden (Prof. Hildebrandsson, 'Standard,' Dec. 26).	Nov. 27.	Beautiful and strange red sky after sunset.
Randers; Stenderup; Jorgensberg, Denmark (MS.)	Nov. 27.	Glows seen.
Newhaven, Connecticut, U.S.A. (Prof. Hazen, Symons's 'Met. Mag.,' vol. xix., 1884, p. 37).	Nov. 27.	Bright after-glow. Fire engines called out.
United States ('Science') ..	Nov. 27 to end of Dec.	Glows conspicuous.
Poughkeepsie, on Hudson ('Nature,' January 3, 1884).	Nov. 27.	Intense glow in sky. Fire engines called out in the morning.
Wüstrow and Magdeburg ('Met. Zeitschrift').	Nov. 27.	"Aurora in W.S.W." After-glow.
Sunderland (Mr. Backhouse, MS.).	Nov. 27.	Blue spot with pink semicircle opposite the sun.
North and South-east coast of France ('Comptes Rendus,' December 3, 1883).	Nov. 27.	The glows conspicuous from this date. Frequently alluded to by observers as aurora borealis.
Tarascon, France ('Comptes Rendus,' December 17, 1883).	Nov. 27.	Glow observed. M. Gasparin states, in 'Comptes Rendus' for February 4, 1884, that the after-glows were observed continuously from November 19, 1883, to January 23, 1884.
Belgium ('Met. Zeitschrift,' March, April, 1884).	Nov. 27.	First glows.
Great part of North Germany ('Met. Zeitschrift,' March, April, 1884).	Nov. 27.	Glows observed.
Vienna ('Austrian Zeitschrift')	Nov. 28.	Glow first generally observed. Lasted till near 6 p.m., resembling a great fire or aurora.
Trient ('Austrian Zeitschrift')..	Nov. 28, 29.	Magnificent glows. Very fine at 5.45 p.m.; and supposed by some to be aurora borealis.
Dalmatia and Corfu ('Austrian Zeitschrift').	End of Nov.	Glows.

Place.	Date.	Notes.
Lesina ('Austrian Zeitschrift').	Nov. 28, 29, 30, &c.	Intense glows. Max. December 1.
Wochein ('Austrian Zeitschrift,' 'Met. Zeitschrift').	Nov. 28, &c.	Glow. At Oberkrain and Wochein began before 6 a.m., and in the evening lasted till 6.30 p.m.
Laibach ('Austrian Zeitschrift,' 'Met. Zeitschrift').	Nov. 28.	Very fine glow like a fire. On 29th, like aurora, till 6.45 p.m. On December 5 the greatest intensity was at 5.40 p.m.
Tabor ('Austrian Zeitschrift').	Nov. 28.	Glows began. Very intense on November 30, lasted till 6.30 p.m.
Berlin ('Austrian Zeitschrift,' 'Met. Zeitschrift').	Nov. 28, &c.	Glows began. One evening the first glow sank on the horizon 50 minutes after sunset; then, after 5 minutes, secondary covering more than half the sky.
Pera ('Austrian Zeitschrift') ..	Nov. 28.	Glows began; duration after sunset one hour.
Munich ('Austrian Zeitschrift,' Professor von Bezold).	About Nov. 28.	Glows observed.
Meran—46° 41′ N. 11° 8′ E. ('Austrian Zeitschrift,' 'Met. Zeitschrift').	Nov. 28.	Glows seen. A slight glow was observed on the 26th. On 28th, corona and very splendid evening glow.
Turkey and Angora ('Austrian Zeitschrift').	Nov. 28.	Glows seen; lasted one hour.
Hanover ('Met. Zeitschrift') ..	Nov. 28.	Glows seen.
Halifax, Nova Scotia ('Knowledge,' February 8, 1884).	Nov. 28.	After-glows observed from this date; lasted from 5.30 to 6.15 p.m.
Bristol (Dr. G. F. Burder, MS.)	Nov. 28.	Magnificent sunset, finest.
Austria (Dr. Hann, 'Standard,' December 26, 1883).	Nov. 28.	Intensely deep-red sky after sunset, also 29th, supposed by some to be a fire.
Sullerupgard, Denmark (MS.) .	Nov. 28.	Glows seen.
Beaumaris, N. Wales ('Daily Chronicle,' December 5).	Nov. 28.	First appearance of glows.
Kirkcaldy ('Scotsman') ..	Nov. 28.	Bright after-glow.
Centreville, Wisconsin (Signal Service Report).	Nov. 28.	At 7.30 p.m. whole southern horizon bright crimson, from W. to S.E.
Arnsberg, Germany (Busch) ..	Nov. 28.	Glows.
Rome, Naples, Brindisi ('Met. Zeitschrift').	Nov. 28 to 30.	Splendid glows. On November 28 and 29 whole sky lit up.
Lugano, Switzerland ('Met. Zeitschrift').	Nov. 28, 29, 30.	Very intense after-glows.

PLACE.	DATE.	NOTES.
Viareggio, Italy ('Standard') ..	Nov. 28.	Splendid after-glow.
Geneva ('Met. Zeitschrift') ..	Nov. 28.	From this date splendid morning and evening glows.
Rome ('Times' correspondent; see 'Nature,' Dec. 6, 1883).	Nov. 28.	Magnificent crimson glare like aurora.
Courtenay, Loiret ('Met. Zeitschrift').	Nov. 28.	Splendid colourless circle round sun.
Castasegna and Sils-Maria, Switzerland ('Met. Zeitschrift').	Nov. 28, 29, 30.	Till about 6 p.m. splendid glow.
Hamburg and the greater part of Germany ('Met. Zeitschrift')	Nov. 28, 29, 30.	Very fine and intense glows.
Amiens ('Nature,' December 20, 1883').	Nov. 28 and Dec. 1.	Greatest intensity of glows 28th and December 1.
London ('Times,' &c., November 30).	Nov. 29.	From about 5.30 to 7.30 a.m. dark-red sky, supposed by many persons to be from a fire. Sunrise 7.43.
Scarborough ('Daily Chronicle,' November 30).	Nov. 29.	Extraordinary sunrise.
Bray, Ireland (Mr. R. M. Barrington, 'Nature,' December 13, 1883.)	Nov. 29.	At 4 a.m. rosy hue.
Copenhagen ('Comptes Rendus,' December 10, 1883).	Nov. 29.	Glows began. Lasted till 6 p.m. after sunset.
Christiania (M. Fearnley, Director of Christiania Observatory. 'Comptes Rendus,' 1883, p. 1517).	Nov. 29.	Glow observed.
Slangerup, Denmark	Nov. 29.	Glows.
Videbok, Denmark—56° 6′ N. 8° 39′ E. (Hoffmeyer, 'Standard,' December 26).	Nov. 29.	Very fine after-glow. High cloud-stratum like drapery.
Videbok, Denmark (MS.) ..	Nov. 29.	Red light on western sky first seen. Very bright, the most beautiful red the observer had ever seen.
Trient ('Met. Zeitschrift') ..	Nov. 29.	Duration till 5.45 p.m.
Ischl ('Met. Zeitschrift') ..	Nov. 29.	Duration of very intense glow till 6 p.m. On December 1st, morning glow began at 5.30; very grand at 6 a.m. Sky seemed to be covered by a delicate veil.

Place.	Date.	Notes.
Jauerberg, Carinthia ('Met. Zeitschrift').	Nov. 29 to Dec. 2.	Glows from 6 a.m. On November 29th magnificent.
Switzerland ('Met. Zeitschrift,' &c.)	Nov. 29, 30.	Glows.
Davosplatz, Switzerland (Mr. J. A. Symonds, in 'Pall Mall Gazette').	Nov. 29.	Rosy flame like northern lights long after the ordinary glow had disappeared. Sun surrounded by opalescent haze.
Germany ('Met. Zeitschrift') . .	Nov. 29, 30.	Glows general.
Whole western half of Austria; South Dalmatia to north border of Bohemia ('Austrian Zeitschrift').	Last days of Nov.	A quite extraordinary morning and evening glow observed.
Kremsier	Nov. 29.	Glows.
Algiers	Nov. 29.	Glows began.
Madrid (Mr. McPherson, Mr. Gillman, 'Nature,' and 'Times').	Nov. 30 or before.	Glows began.
Naples (Padre Denza, 'Nature,' Dec. 20, 1883).	Nov. 29.	Whole sky lit up.
Marianborg, Denmark	Nov. 30.	Glows observed.
Lerwick, Shetland Islands . .	Nov. 30.	Marvellous sunsets, beginning before this date. About 5 p.m., on Nov. 30, the whole southern sky was tinged with a brick-red light, like the glare of a great conflagration.
Six-Mile Bridge, Co. Clare, Ireland (Rev. E. Lloyd, MS.)	Nov. 30.	Very fine sunset.
Worcester, England (Mr. Bozward, 'Nature,' Dec. 6).	Nov. 30.	At 5.15 p.m. red arc 25° high.
Frauenfeld ('Met. Zeitschrift,' 'Austrian Zeitschrift').	Nov. 30.	Splendid after-glow. First notice of the glows. Duration 1 hour 52 minutes.
Warsaw ('Met. Zeitschrift,' 'Austrian Zeitschrift').	Nov. 30.	After-glow till 5.30 p.m. Described as zodiacal light.
Sweden (Hildebrandsson, 'Standard,' Dec. 26th).	Nov. 30.	First general observation of glows. At Upsala, at 4.30 p.m., the whole sky was transformed into a red cupola.
Basle to Calais (on the way from).	Nov. 30.	Magnificent morning glow from 5.30 a.m., and evening glow till 6.30 p.m.
Cape of Good Hope ('Met. Zeitschrift').	Nov. 30.	Glows.

Place.	Date.	Notes.
San Salvador, Central America ('Met. Zeitschrift,' March, April, 1884).	Nov. 30.	Glows seen.
Asante—19°·6 N. 56°·9 W. ('Met. Zeitschrift').	Nov. 30.	Pretty strong after-glow.
Druskeniki, Russia (MS.) ..	Nov. 30.	Glows observed.
Zi-ka-wei (Shanghai)	End of Nov. (?)	At the beginning of December the glows nearly ceased, but after a few days their intensity was renewed.
Mobile, U.S.	End of Nov.	Maximum last week of November and first week of December.
Stockholm and Christiania ('Nature,' December 20, 1883).	Nov. 30.	First glows. Lasted from November 30 to middle of February. Intense after-glow like a great conflagration on November 30.
La Hendaye, France ('Nature,' Dec. 6, 1883).	Nov. 30.	Glows observed.
Fredericton, New Brunswick (W. Brydone Jack, 'Nature,' January 17, 1884).	Nov. 30.	On this day whole heavens red before sunrise.
British Isles, France, Switzerland, Spain, Constantinople, Lesina, Marseilles ('Times,' &c.).	Dec. 1.	Great intensity of glows. At Constantinople duration 1½ hour. In London the glow was visible behind clouds till 5.45 p.m.
Louvain, France	Dec. 1.	At 4.25 p.m. western horizon greenish-blue; rosy glow to zenith.
Marburg ('Met. Zeitschrift') ..	Dec. 1.	Marvellous glow, bathing the landscape, at 6 a.m.
Rome (Mr. T. Henderson, MS.)	Dec. 1.	First remarked glow.
Nice	Dec. 1.	First glow lasted to 55 minutes, second to 90 minutes after sunset.
Freiburg	Dec. 1.	On this date the glows were at their maximum; glow very intense two hours before sunrise.
Brixen ('Austrian Zeitschrift')	Dec. 1.	Began before 6 a.m. Lasted till 7 p.m. after sunset. Very fine glow like aurora borealis.
Gmünden ('Austrian Zeitschrift').	Dec. 1.	Flaming red 6 a.m. Blood-red 5 to 6 p.m.
Salzburg ('Austrian Zeitschrift').	Dec. 1.	Most brilliant from 6 a.m.
Orange, France	Dec. 1.	At 6.15 a.m. appearance of a tremendous fire raging. At 6.20 it seemed as if the sun were about to rise. At 6.40 extensive yellow, at 7 greenish. After-glow visible till 7 p.m.

Place.	Date.	Notes.
Grauheim—61°·1 N. 8°·6 E. ..	Dec. 1.	Evening glow; also January 1 and February 27.
Kiel ('Met. Zeitschrift,' March, April, 1884).	Dec. 1.	Whole sky bright red and violet after sunset.
Malta	All through Dec.	Glows.
W. Austria, Dalmatia to N. Bohemia ('Zeitsch. für Met.')	First few days of Dec.	Glows.
Europe generally, excepting Russia.	Dec. 1.	Glows brilliant.
Athens ('Daily News,' Dec. 8).	About Dec. 1.	Brilliant after-glows seen every morning and evening from about this date. The displays at sunrise and sunset lasted fully 1½ hour.
United States, *e.g.*, Archer (Florida), Andersonville (Georgia), Oskaloosa (Iowa), Fort Scott (Kansas), Genoa (Nebraska), Portland (Oregon), &c.	Dec. 1.	Glows.
Upsala	Dec. 1.	Sunrise extraordinarily splendid.
Videbok, Denmark (MS.) ..	Dec. 1.	Marvellous light redness after sunset. White brightness till 2 hours after sunset. Olive-green in N.W. for a similar time.
Honolulu	Early in Dec.	The glows were renewed, and as brilliant as in October.
Akureyri, Iceland (MS. from Akureyri, dated Feb. 2, 1884).	Autumn.	"Just since autumn a most peculiar phenomenon—a dark-red light on horizon, sunrise and sunset, and olive-green in north-west, just like what may be seen at great volcanic eruptions."
Crimea	In Dec.	Glows.
Mauritius	In Dec.	Glows continued. After-glow began 14 minutes after sunset and lasted 24 minutes. 2nd glow began 38 minutes after sunset and lasted to 1 hour 17 minutes. In the morning the first glow appeared at 1 hour 26 minutes before sunrise.
Reykjavik, Iceland	During Dec.	Glows.
Vittoria, Spain		In December the glow was observed to last 1 hour 45 mins., and on another occasion 1 hour 56 mins.
Riviera, Italy	Dec.	The glows continued through the month.
Russia (MS.)	During Dec.	The glows were observed from Belostok, 53° N. 23° E. in the west, to Perm, 58° N. 57° E., in the east.
Pulkowa, Russia	Dec.	The twilight lasted when the sun was more than 18° below the horizon.

PLACE.	DATE.	NOTES.
San Salvador, Central America	Dec. 2, &c.	Glows this day and during the month.
Valence, France..	Dec. 2.	Duration of glow till 6.16 p.m.
Naples (Johnston-Lavis, 'Daily News,' December 8, 1883).	Dec. 2.	Morning red at 5.30. "First the glow was low on the horizon, then it spread up into some invisible mist high in the sky, afterwards it faded away, and a curious yellow glare overspread the landscape, and when, as long after as 7.15, the sun at last peeped above the mountains, that luminary was dazzling white, like an electric lamp. Bluish moon and remarkable sunset.
Madrid (Gillman, 'Nature,' December 20, 1883).	Dec. 2.	Evening red till 6.15 (sunset 4.24); very intense till 6 p.m.
Rome	Dec. 2.	Glow magnificent.
Sydney, N.S.W. (Mr. Hargrave's MS.)	Dec. 2.	Sunset 6.55; white haze 7.6; pink 7.10, and moon steel-blue; pink on horizon, turned yellow 7.30; 2nd glow began 7.40; all over, 8.35.
Röraas—62° 35′ N. 11° 23′ E.	Dec. 2.	Extraordinary glows, 3 to 4 p.m.
Stenkjeer—64° 1′ N. 11° 25′ E. ..	Dec. 2.	Extraordinary glows 3 to 4 p.m.
Asante—21°·3 N. 55°.6 W. ('Met. Zeitschrift').	Dec. 2.	Fiery glow.
Europe and North America, India, Australia, North Atlantic, Indian Ocean, part of the Pacific Ocean, New Zealand.	Early in Dec.	Glows very strong.
Lisbon (Captain De B. Capello, 'Standard,' December 26).	Dec. 3.	Sunset about 4.35. Glow up to 60° at 5.18. Disappeared 6.30.
Madrid (Mr. Gillman, 'Nature,' December 20).	Dec. 3.	Cloud-ripple and glow. On December 4 red sky till 6.15.
Oberbürgermeister von Winter—32° N. 24° W. ('Met. Zeits.').	Dec. 3.	Sky copper-red at sunset.
Crete—35° N. 25° E. ('Pall Mall Gazette,' December 5).	Dec. 4.	Very brilliant "aurora" 5 to 8 p.m. Rays blue, crimson, and pink.
Oder—40° N. 72° W. ('Met. Zeitschrift').	Dec. 4.	Very strong morning glow, like aurora.
Richmond, Surrey (Hon. R. Russell)	Dec. 5.	The first appearance of a glow in the west on this day began at 25 minutes after sunset, and lasted till 4.50, 55 minutes after sunset. Moon greenish after dark.
Stonyhurst ('Nature,' Dec 13).	Dec. 5.	Strong absorption bands between A and D.
Buda Pesth (Herr Gothard, 'Austrian Zeitschrift').	Dec. 5.	Red end of spectrum extraordinarily developed. Simply a modified solar spectrum.

PLACE.	DATE.	NOTES.
Tunbridge Wells, Kent (Mr. E. D. Archibald, 'Nature,' December 13).	Dec. 5.	Cirriform haze and glow.
England..	During Dec.	The white parallel streaks like cirro-stratus, noticed by many observers. This apparent cloudiness decreased continuously.
50° N. 7° W. ('Met. Zeitschrift')	Dec. 6.	Red corona round the moon.
Wilhelm—50° N. 22° W. ('Met. Zeitschrift').	Dec. 6.	Remarkable red corona round the moon.
N. America, Switzerland, Spain	Dec. 7.	Intense glow.
Richmond, Surrey (Hon. R. Russell's Register).	Dec. 7.	Glow much fainter.
Berlin	Dec. 8.	Streaky greyish-white cloud parallel to the horizon.
Magdalena—44°·7 N. 39°·7 W...	Dec. 9.	From 6 a.m. very bright glow, and also from 5 to 5.45 p.m.
Bellerophon — near Singapore (Met. Office Log).	Dec. 9.	Large halo round moon. A few days later peculiar pale red haze round moon.
Paris	Dec. 9.	The glow lasted 1 hour 43 minutes.
Lochee—28° 46′ S. 29° 26′ W. (Met. Office Log).	Dec. 10.	Beautiful bright red sky at sunset.
Corientes—20°·8 N. 22°·6 W. ..	Dec. 10.	Very clear air. At sunrise most extraordinary and alarming colours as before hurricanes in Indian Ocean. This lasted till after passing the Canary Islands.
Magdalena—46°·1 N. 30°·5 W. ('Met. Zeitschrift').	Dec. 11.	Very bright glow from 6.30 to 7.30 a.m.
Kew, Surrey	Dec. 11.	Sky still glowing at 5.27 p.m.
Tournai, Belgium	Dec. 11.	Glow till 5.30 p.m.
Angora, Asia Minor ('Met. Zeitschrift,' 1884, p. 29).	Dec. 12.	Glow seen.
Kiachta, Siberia ('Times') ..	Dec. 11 to 25.	Brilliant after-glows.
Asante—28°·4 N. 54°·1 W. ..	Dec. 13.	Strong glow.
Oberbürgermeister von Winter—19°·3 N. 23°·5 W. ('Met. Zeitschrift').	Dec. 13.	Leaden-coloured sky, and 1 hour after sunset blood-red.
Sunbeam—35° 22′ N. 46° 10′ W. (Lady Brassey).	Dec. 13, 14, 15, 16.	Most magnificent sunrises and sunsets, with secondary glows like northern lights. On December 16 the entire sky suffused with clear orange colour, fading into delicate bluish-green.

PLACE.	DATE.	NOTES.
Mercur — 19°·6 N. 34°·5 W. ('Met. Zeitschrift').	Dec. 12 to 14.	Reddish-yellow sheen round moon. On 13th the sun had a similar sheen.
Magdalena—47°·8 N. 21°·3 W. ('Met. Zeitschrift').	Dec. 13.	Strong glow from 6 a.m. to 7.30.
Tai Yuen Fu Shansi, China ('Nature,' May 22, 1884).	In Dec.	Glows.
Réunion	Dec.	Glows rapidly diminished from the middle to the end of December, when they ceased.
Stonyhurst, Lancashire (Rev. S. J. Perry, F.R.S.)	Dec. 16.	Maximum on this day. Glow visible till 1 hour 50 minutes after sunset.
Magdalena—49°·3 N. 6°·9 W. ('Met. Zeitschrift').	Dec. 16.	Very bright glow 6 to 6.45 a.m. and 5 to 6 p.m.
Crimea	Dec. 16.	Very fine glow, supposed "aurora."
Sunbeam—36° 57′ N. 38° 22′ W.	Dec. 17.	Magnificent sunset, bright reds and greens. On December 18 and 19 whole sky coloured.
Berlin	Dec. 17.	The illuminated sky distinctly striated.
Vadsö—70° 4′ N. 29° 45′ E. ..	Dec. 18 to 25.	Glows strong 3 to 4 p.m.
Asante — 35°·2 N. 46°·2 W. ('Met. Zeitschrift.')	Dec. 19.	Strong glow.
Aalesund, 62°·3 N. 6°·9 E. ..	Dec. 20.	Glow 4.30 to 5 p.m.
Torungen, 58° 25′ N. 8° 48′ E.	Dec. 25.	Glow from sunset to 6 p.m.
Asante—36°·1 N. 42°·6 W. ('Met. Zeitschrift').	Dec. 21, 22.	Strong glow. On 22nd over nearly the whole sky.
Sydney, N.S.W...	Dec. 25.	Sunset 7.12. First glow setting and second glow appearing 8 p.m., red still visible 8.45.
Puy de Dôme, Auvergne ..	Dec. 27.	At 6 p.m. light enough to read by.
Thessalus—27° 27′ S. 50° 45′ E.	Dec. 28.	From 7 to 8 p.m. sky after sunset assumed a great variety of tints most beautifully mingled. Same on 30th in 28° 43′ S. 45° 3′ E., and on many other days. On January 1, 1884, before sunrise, blood-red. On January 12, at 4.30 a.m., in 35° S. 19° E., sky red to the eastward.
Hankow, N. China	Dec. 29.	Green sun and red glow.
Pekin, China (Report of Pekin Hospital, 'Met. Zeitschrift,' March, 1884).	End of Dec.	Glows.

PLACE.	DATE.	NOTES.
Dresden	Dec. 30.	Astronomical twilight lasted till 6.24 instead of till 6.4 p.m.
Hamburg	Dec. 31.	At 5.20 p.m. glow strong enough to cast shadows. At 5.54 second glow ended.
Europe and America	End of Dec. 1884.	Great intensity of glows. At Ben Nevis, on December 30, colours most magnificent.
Europe and North America ('Met. Zeitschrift,' March, April, 1884).	Jan., Feb., Mar.	The glows were generally observed through January and February, and steadily declined till in most places they became invisible in March. In the province of Vitebsk, Russia, they were noticed at the beginning of March, as soon as the clouds, which had obscured them for 3 months, cleared off. The decline of the glows was marked by shorter duration, fainter coloration, and absence of the secondary illumination. Their decrease was far more gradual than the rapid increase in November, 1883. On January 24, 1884, Professor Karlinski saw at Cracow a splendid green sun.
Europe and North America ..	April to Dec., 1884.	Occasional crepuscular displays were seen in the course of the summer and autumn, but seem to have been more local than general, and not comparable in brilliancy with the earlier phenomena.
North Atlantic	1884	There is not much evidence of the continuance of the glows over the ocean; but in January especially it was occasionally observed. As a rule, the phenomena had become so common as no longer to be noted. Near Madeira the glows were fine till the end of March. On February 18 and 24 they were observed at 36° N. 36° W. and 25° N. 28° W. In 16° N. 42° W., on March 25 the sunset was magnificent, with fine lines of cirro-stratus and a dark red glow.
Australia, New Zealand, and the Southern Indian Ocean.	1884.	Glows occasionally fine in February and March, but very fitful and sometimes not seen at all on clear days. The duration continuously decreased. Some fine glows in Australia several times between March and October. Pink glow still visible at Nelson, N.Z., on July 1 and 2. On February 24, in 10° 3′ S. 99° 53′ E., the western sky was brilliantly yellow for about half an hour. On March 3, in 18° 34′ S. 82° 17′ E., there was a peculiar green in the sky before and after sunset.
India and China..	1884.	At Poona, in India, on January 8, the blood-red skies are reported as beginning to fade. In China the glows continued during January.

PLACE.	DATE.	NOTES.
Central America	1884.	The maximum glow at Panama was on January 9.
South Africa	1884.	Glows conspicuous in March, April, and June.
Bourbon Island	1884.	The crepuscular phenomena were very fine in April.
South America	1884.	At Monte Video the after-glows continued in March.
Tavoy, Burmah (Mr. Wallace, MS.)	1884.	The glows were observed in January, but were more marked in February and March.
New Caledonia and the Western Pacific ('Nature,' March 13, 1884).	1884.	The glows continued in January.

F. A. ROLLO RUSSELL.

PART IV., SECTION III. (A).

GENERAL GEOGRAPHICAL DISTRIBUTION OF ALL THE OPTICAL PHENOMENA IN SPACE AND TIME; INCLUDING ALSO VELOCITY OF TRANSLATION OF SMOKE STREAM.

By the Hon. ROLLO RUSSELL.

GEOGRAPHICAL DISTRIBUTION OF PECULIAR SKY PHENOMENA.

In the early part of 1883 we find two or three notices of fine sunsets; but no special report of them was made at the time by any competent observer, nor, as far as we can learn, were these sunsets distinguished in any respect from those displays of a beautiful and quiet character which may occur in any year, and almost any climate. The most noteworthy observations are those of Mr. NEISON, Director of the Government Observatory at Natal.* He says that on February 8th, 1883, he made a sketch of one of the sunsets which began to be noticeable about that time. The sketch has unfortunately been destroyed. They were on a less grand scale than those of the following autumn, but became gradually more marked till June. Then for two months nothing was noticed. On August 21st and 22nd they were noticeable, but not vivid. On August 28th and 29th they were most vivid, and till September 5th the vivid

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* 'Knowledge,' June 6, 1884.

redness of the sky was most remarkable, fading away into green and purple in the east. After this the uncommon sunsets did not recur for four months, except in a very faint degree. In February and March, 1884, they again became very noticeable, but early in April, 1884, had again disappeared. Mr. NEISON'S account is difficult to interpret, as reports from the Transvaal, the Cape, and the Ocean east and south, give details of extraordinary glows seen first early in September, then from September 20th continuously through October and November, 1883. He observes that at only 250 miles distant, in the Transvaal, the glows were most vivid until the end of January, 1884. With regard to the sunsets of May and June, 1883 (the exact dates are wanting), in Natal, it may be worth noting that the first eruption of Krakatoa occurred on May 20th, 1883; and as to the sunsets of August 21st and 22nd, we now know that from August 11th to 18th the volcano was emitting enormous volumes of smoke and dust, causing showers of sand and ashes.

A remarkable sunrise was seen from the *Tilkhurst* on May 22nd in 33° S. 29° E., a peculiar sunset in 39° 18′ S. 93° 25′ E. on May 24th, and a red sky at sunset in 36° N. 3° W. on June 1st.

A white haze and strong glare were seen on board the *Viola* on May 24th in 16° 11′ N. 26° 55′ W.; and on May 27th, in 9° 59′ N. 28° 9′ W., the haze continued, with a fall of reddish sand, and the sun looked like melted glass.

If Krakatoa be assumed to be the origin of these last phenomena, the products of the eruption must have been carried in a direction a little north of west at the rate of about 100 miles an hour, but the effects in this case were much more probably owing to sand from the African desert.

On July 16th and 17th there were a bright yellow sky and blue moon after sunset in 8° 52′ N. 85° 52′ E., accompanied by other phenomena greatly resembling those which afterwards occurred over a wide area in September.

After the May eruption the dust must have travelled south-westwards at the rate of about 103 miles an hour, if the scarlet clouds at sunrise seen on board the *Tilkhurst* were due to its having affected the neighbouring part of the atmosphere; but it seems not improbable that the sun in rising may have been reddened by this dust in the upper atmosphere 8° to 10° further east, as the *Tilkhurst* has no record of a correspondingly brilliant sunset on May 22nd. In that case the velocity did not exceed 93 miles an hour. Little reliance, however, can be placed on the few observations of this period, which do not distinctly record phenomena of an extraordinary character. The peculiar sunset in 39° 18′ S. 93° 25′ E. would show a rate of about 25 miles an hour.

The bright sunsets of August 21st and 22nd, in Natal, if due to the activity of Krakatoa on August 11th, would also show a rate of about 25 miles an hour.

A beautiful sunset, but nothing more, was reported from Nashville, Tennessee, as having occurred on August 22nd, 1883, and one was reported from Logansport, Indiana, on August 14th.

Colonel WARD, at Partenkirchen, Bavaria, noticed some fine red sunsets, with *Alpenglühen*, in Bavaria, in the early part of the summer of 1883, especially in June,* and recorded them in his register at the time.

With the exception of the observations of July 16th and 17th in the Indian Ocean, there appears to have been no striking manifestation of abnormal twilight phenomena before August 26th, 1883. Even on and after this date some of the slighter phenomena may have been due to the previous activity of Krakatoa, and to the eruption of Gunong Api, Moluccas, on the night of August 25th, 1883. An eruption at Sandalwood Island, seen by the Rev. J. E. TENISON WOODS † in August, may possibly have produced some of the effects noticed. But the observations made on board the *Belfast*, and other ships, towards the end of May, and in June, indicate the probable existence of a very rapid upper current from the Strait of Sunda in a south-westerly direction. The later observations of August, coinciding with an actual fall of dust, make it certain that in that month such a current existed, not dependent on the direction of the variable lower winds.

On August 26th, on board the *Ardgowan*, in 7° 54′ S. 85° 37′ E., the sky looked "all of a flare;" in 5° 38′ S. 106° E. the clouds were red and yellow; in 1°·7 S. 93°·2 E. the whole sky was of a peculiar red, like bright-polished copper; and at Foochow, 26° 7′ N. 119° 18′ E., there was a light like aurora borealis. About 50 to 100 miles south of Java's First Point the sky was extremely overcast, and ashes fell during the 26th, explosions having been heard during the previous night. Evidently, by the evening of the 26th, a very considerable area in the Indian Ocean south and west of Krakatoa was subject to unusual phenomena. On the morning of the 27th, at Telok Betong, near the Strait of Sunda, the sky was of a copper colour; at places in Ceylon the sky was murky in the morning; and a green sun was seen in the evening. Between 4 and 5 a.m. on the 27th there was a red illumination of the sky at Semanka. At about 90 English miles north-east of Krakatoa the sky was pale yellow, of changing hues, at 4.30 a.m. The sun, on emerging from the dark cloud of ashes, was seen green at Batavia on August 27th. Peculiar effects on the sun and sky seem to have extended rapidly in a N.N.E. direction, for they were seen at Labuan and Banguey Island on or about August 27th, and in Japan on August 29th, 30th, and 31st; also at Cheefoo on August 29th, in 37° 24′ N. and 121° 25′ E. If the appearances in Japan were due to the eruptions in the early afternoon of the 26th, the haze must have been carried by an upper current at about 47 miles an hour in that direction. The upper clouds observed in the preceding fortnight, during the voyage of the *Scotia* from Japan to the Indian Ocean, show that an upper current from between south and west prevailed as far as about 27° south, and then changed to north-east, while the lower wind was south-west.

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* MS., and SYMONS's Monthly 'Meteorological Magazine.'

† Sydney 'Morning Herald,' January 16, 1884.

Another current seems to have conveyed a portion of the ejecta in an easterly direction, for on September 1st, at New Ireland, 3° S. 152° E., and on September 3rd at New Hanover, the glare was observed, and a fall of dust occurred off the north-west Cape of Australia on August 30th.

The mass of the ejecta seems to have been carried with great velocity westwards and south-westwards at a very high level. Already on August 27th the atmosphere at Seychelles, Rodriguez, Diego Garcia, and Mauritius was affected by a haze. This may have been partly due to eruptions on the 25–26th and 26th, or to the almost continual eruptions of the previous week, but by six in the evening the appearances at the Seychelles were of a striking character. In the evening the haze was strong enough to cause a red glare at the three islands first-named, which lasted till 7.15 p.m. The haze between Krakatoa and Madagascar is noticed in several logs on the 27th, and as far west as 91° E. there was a fall of dust from the 27th to the 29th. The *Tweed* had a fall of ashes at about 370 English miles from Krakatoa in the direction of Keeling Islands. And at Keeling, or Cocos, Islands, dust fell thickly from 4 p.m. on August 27th. On the 28th, in 9° 15′ S. 93° E., the sky was white and the sun reddish-yellow, with a shower of sand, and at 6° 12′ S. 88° 17′ E. the sky was very hazy, a constant shower of white powder falling. At this longitude the haze and fall of ashes extended to about 8° S. at least, probably much further; and at 6° N. there was a complete circle round the sun, but nothing else unusual was noted. On the 28th, while ashes fell in Sumatra, and dust as far as 1140 English miles west of Java Head, the sun was much obscured, as by a fog, at the Seychelles, and was also dim, with a strange sky, at Diego Garcia and St. Brandon. At Mauritius there was a crimson dawn and the sun was red after rising; while in Natal on August 28th and 29th most vivid sunsets were noticed. At 25° S. 61°·5 E. there was a bright sky in the evening of the 28th. Thus a dense band of haze seems to have existed on this day within a few degrees of a line drawn from Krakatoa to the Seychelles, with falls of dust along about one-third of that distance; while much further south the matter in the upper air caused brilliant effects after sunset or before sunrise. The twilight effects so far, preceded the obscuration of the sun; in Japan a red glow was seen from 12 to 24 hours before the sun was notably dimmed. The reason for this becomes evident by further following the propagation of the haze; wherever it was dense the red twilight effects were little noticed or absent. Thus the red twilight of August 27th in the western part of the Indian Ocean was probably caused by a thin haze in the upper air proceeding from the eruptions before the great outburst of the 27th. The green sun affecting a small part of Ceylon on the 27th and following days may have been caused by an intermediate current bearing northwards some of the thick dust which, according to the *Brani* and other vessels, must have been falling from the main E. to W. stream at a high level during the 27th, at 3° S. 92° 11′ E., and probably much further westwards. A variety of currents must have existed between the surface of the earth and a high level; for, the dust or haze was in a short time widely distributed in various directions. Mr. Verbeek mentions the probable existence of two currents, one from south-east and the other from north-east, by which the dust was transported. But the products of the 27th seem to have been so largely projected to a very high level that they were carried swiftly in a westerly direction without immediately affecting latitudes much north or south of the volcano in a greater degree than the eruption of the 26th, except perhaps as regards Japan. The green sun of the 27th at Ceylon and Labuan lasted only a short time, and was not generally observed in any large area. In fact, the absence of green or blue suns in the Indian Ocean before September 8th deserves particular notice.

On August 29th, from about 6° S. 88° E. to 2° 37′ S. 79° 52′ E., and probably over a very large extent of the Indian Ocean, dust was falling and the sky was very hazy, the sun being nearly obscured, both on this day and on the 30th, by a pale yellowish haze. On the 29th a remarkably coloured sky was seen at 44°·6 N., 52°·9 W., and at 55° 56′ S. 62° 51′ W., but these observations are isolated. Possibly, considering the manner of the distribution of later effects, they were due to some of the considerable eruptions of August 11th, 14th, and 16th ; and the fine sunsets of August 21st and 22nd at Natal would similarly be due to the propagation in a south-westerly direction of the products of those eruptions. At the same time it should be borne in mind that a great storm was passing a little south of 44°·6 N. 52°·9 W. on August 29th, which may presumably have been concerned in producing the colours there noticed.

On August 30th the first phenomena of a peculiar character were observed in a few places west of Africa. A remarkable sky was noted at 10° N. 26° W. and 2° 30′ S. 20° W. after sunset, and as far west as Maranham, about 2° 30′ S. 44° W. ; but the most interesting observation is that from St. Helena, 16° S. 6° W., where at 4 a.m. on the 30th a red light in the south-east and south-west, "like a fire," alarmed one of the inhabitants. This was the first instance of a comparison to a fire, which was afterwards frequent. The glow still prevailed far south in the Indian Ocean, at 26°·5 S. 56°·5 E. A fall of dust off the north-west coast of Australia added to the evidence of a surprising variety of intermediate upper currents.

On August 31st, in 1° 20′ S. 21° W., at 8 a.m. the sun was coppery, and at 2°·3 S. 4°·7 E. veiled with a silver-white sheen, and strange appearances extended from 13° 33′ N. 31° 29′ W. to Natal, and probably much further west in that latitude. At Maranham the sun was dim at 7 a.m.

On September 1st the blue sun band extended across the Atlantic from east to west, reaching even to Guayaquil at 80° W. in the latitude of 2° S. ; and between 12°·7 S. 27°·3 W. and 10° 40′ N. 26° 30′ W. in the mid-Atlantic. The sunset glow appeared at Santiago, Chili, 33° S. 71° W. about this time, and a remarkable sky was seen long before sunrise in 11° N. 25° 27′ W., but there is no mention of it further west in north latitudes.

On September 2nd the whole northern part of South America, between the

Antilles and Peru, and between Panama and Paramaribo, seems to have had a blue sun; and in many places a red light was seen long after sunset. A grey sky still covered the Atlantic, and at 4° 41′ S. 31° 10′ W. the sun, about 5 p.m., was pale blue. Meanwhile, as far as 36° S. 21° E. in the south-western part of the Indian Ocean, there were splendid twilight colours.

At 4 a.m. on September 3rd, in 7° S. 33° W. the northern horizon was very red, and at 7 a.m. the sun was pale blue. At 8°·2 S. 34°·6 W. the air was grey and hazy; but there is no mention of a blue sun. A fiery sky and white sun were seen at 3° 6′ S. 27° 4′ W. The glows reached Cape Town, Africa, and 17° N. 125° W. in the Pacific.

It is plain, so far, that the phenomena did not occur simultaneously in places situated on the same degree of longitude, and that they differed greatly in intensity at places not far apart. South of the Equator there is little mention of a blue sun, but much of a persistent grey haze in the upper air.

On September 4th the green sun reached as far west as Fanning Island, in 3° 30′ N. 159° 22′ W., and the sun was copper-coloured in the afternoon, giving rise to considerable anxiety, while at 16° 5′ S. 148°45′ W. there was a remarkable sunset glow. At 10° 19′ N. 161° 21′ W., in the morning the sky was covered with a thin white layer, through which the sun penetrated, and the atmosphere looked yellow and watery. This peculiar haze was noticed from this time continuously for many days by the captain of the *Papa*. At 8° 20′ N. 155° 28′ W., both a green sun and strange sky colorations were seen in the evening by the captain of the *Jennie Walker*. The light haze over the sky, and silver sun, seem to have reached as far as Tapiteuea (1° 10′ S. 174° 50′ E.) on this day, or the 5th by Eastern time.

On September 5th the zone of blue or green sun in the Pacific reached as far north as 21° 30′ N. for a short time, and southward at least as far as 13° 17′ S., and in breadth was wider than hitherto. The haze, which was dense at 8° 1′ N. 161° 4′ W., was hardly perceptible at 21° 30′ N., but the red light seen after sunset at the latter point did not show itself at the former. The afterglows now began to be noticed in the Transvaal.

Early on the following day, September 7th by Eastern time, the sun was blue at 5° N. 163° 6′ E., and coppery at the Equator in 172° E., but there is no means of ascertaining how far west and how far north and south the phenomena extended on this day. From September 7th to 9th there was a startling redness of the eastern sky off the coast of America between New York and C. Canaveral. About the same time the red sunsets seem to have appeared in Virginia and the Southern States.

On September 8th, Eastern time, the haze continued dense in the Pacific. On September 8th, Western time, a red sunset was observed in Florida, and at Chelsea and Haslemere in England, but there was no continuance in England of any remarkable after-glows.

On September 9th a greenish sun was seen at 10° 30′ N. 122° E., and the sun was blue or green in Ceylon, in about 8° N. 88° 44′ E., in 16° 56′ N. 87° 17′ E., and in 12° N. 51° E. In 37° 06′ S. 40° 46′ W. there was a pale yellow haze at noon; and, after 6 p.m., a very wonderful sunset. In New Zealand, 41° S. 174° 44′ E., the fine sunsets began. From September 9th to 12th a green or blue sun was visible over a great part of India On September 9th there were fiery sunrise and sunset glows at about 28° N. 80° W.

There can be no doubt, from a comparison of the data given in the general list, that the blue sun and yellow haze passed round the world from east to west in a gradually widening zone, and that the matter concerned in producing them was unequally distributed in clouds or streams of different density. The wonderful red twilights were seen only where the haze was much thinner, either before the dense main cloud of matter covered the sky, or after it had passed, or at its edges on the northern and southern borders. Some places had twilight glows for a short period long before they set in regularly; and these glows seem to have been caused by portions of the main stream breaking off or sinking into different currents of air, such as balloon ascents have proved to exist, at lesser elevations. The appearances at Ceylon, from August 27th to September 9th, may have been partly owing to such branch streams, and partly to matter brought at a much lower level more directly from the vicinity of the volcano. The after-glow on September 8th in Florida was probably caused by a detached portion of the great body of matter which had passed a little south of it on September 2nd. The after-glow noticed in some of the southern English counties on September 8th would be accounted for by the heavier particles of the main stream as it crossed the Atlantic from August 31st to September 2nd, dropping into the anti-trade, and being carried to our shores in seven or eight days. This supposition would agree well with the interval shown in Section V. to have elapsed between an eruption in the Azores and twilight phenomena in England. Another not improbable supposition is that these slight after-glows were caused by the Krakatoa eruptions of May, 1883, for the interval of three months and eighteen days nearly corresponds with the interval between the August eruptions and the later sky phenomena in Europe.

As regards the breadth of the main stream, the edges of which produced the fiery after-glows, in the first circuit of the world it seems to have extended in the Atlantic at least from 16° S. (St. Helena) to at least 10° or 12° N. Further west it was conspicuous on September 2nd at 11° N. (Trinidad), and at 33° S. (Santiago). Three days later, in the Pacific, it was seen at 22° N. and 13° S., and probably extended much further south in the longitude where seen, 148° 46′ W. There is no evidence of an increase in breadth after this until the first circuit was completed, with the exception of Wellington, New Zealand, 41° S. 174° 44′ E., where splendid sunsets were reported as beginning on September 9th, Eastern time—that is, only three days after Honolulu. Whether these sunset glows were due to the fringe of the main stream passing by, or to an offshoot from it, cannot be determined.

The denser part of the main cloud of matter in the first circuit, causing a blue, green, or silvery sun, and a yellow or white haze, covered a much narrower area than the after-glows. In the Indian Ocean it seems to have extended from Diego Garcia to the Seychelles on August 28th—that is, between 20° S. and 5° S., and probably some degrees further north; in the Atlantic, between 10° 40′ N. and 14° S., and in the Pacific between 10° 19′ N. and 13° 17′ S., excluding a report of a green sun of short duration at Honolulu. On the coast of China, at 20° N., a green sun and an after-glow were noted on September 10th. A coppery sun was seen at a few places only, near the Equator, namely, 1° 20′ S., on August 31st, off the west coast of Africa; 3° 30′ N., at Fanning Island, on September 4th; and about the Equator 172° E., on September 7th, Eastern time. A coppery sun had been seen at Japan on August 28th with a similar haze of great density, and probably much lower in the atmosphere.

On September 9th, when the main cloud of matter had reached India after a circuit of the earth, its breadth appears to have been greater in the northern than in the southern hemisphere. A green sun was visible over Southern and Central India on September 10th, and in 18° N. 85° 40′ E. Meanwhile, phenomena far south in the Atlantic showed that a quantity of matter had been left in the track of the great cloud, and had drifted southwards. In the Pacific, at 1°·0 S. 165°·1 W., the sky was still thinly veiled, and after-glows continued at Honolulu.

In the second circuit a green sun and moon were seen in the Red Sea to about 14° N. The after-glows were seen as far as 15° N. No green sun is reported from the Seychelles or Mauritius.

On September 12th the first glows reached Muscat, 23° N. 59° E.

On September 14th, in 15°·2 S. 87°·3 E., there was both an intense red glow and a greenish sun. In the Atlantic on September 14th the sun was green as far as 14° 36′ N., but there is no mention of a green sun in that ocean south of the Equator. The after-glows were conspicuous in the Atlantic; and on September 13th the cirro-stratus or haze extended to 14° N., resembling what was seen further south on September 1st. On September 17th the glow was seen in 23° 44′ N. and 18° 41′ W.

On September 15th the after-glows extended to South Australia and Tasmania, about 41° S.

On the 15th and 16th, at Barbadoes, the sun was of various colours.

On September 18th, at 140° 5′ W., the glows extended to 24° N., and at 147° W. the green sun was seen as far as 15° N. On the same day, in the Atlantic, at 20° N., the sky was luminous.

On September 20th the glows began to be seen regularly at the Cape of Good Hope, and were noticed at 34°·9 S. 22°·4 E. and 49°·9 S. 48° W., at 49° N. 20° 16′ W., and in London. (The last were probably sporadic cases.)

They were visible over the northern part of India from September 21st to 30th, and at Santiago, Chili, about 33° S. 71° W.

On September 22nd the green sun had returned to Southern India after a second circuit of the globe, and lasted two or three days as before. After this no well-attested observation of a green or blue sun, except at Duem, 14° N. 32° 30′ E., on September 24th, when it rose green, and at 9° S. 35° W. on September 28th, when it set pale blue, occurs in any contemporary record.

On September 29th, in 5° 13′ S. 35° W., the sun had a whitish appearance, and at 1° 23′ N. 41° 5′ W. on October 1st the sunrise was very pale.

During September the glows were seen continuously in the Pacific, between New Hanover and the Marshall Islands.* From September 20th to 30th, the twilight glows were affecting a large part of the North Pacific, the Indian Ocean, India, and the Atlantic, as far south as 31° S., in 39° 35′ W. On September 30th, the red sunsets are stated to have begun in Brazil, but in many parts they had been long visible at that date. Isolated after-glows were seen in Ireland and Surrey, and at 36° N. 4° W. At Réunion there was a renewal of glows on September 25th.

From October 1st to 10th the glows extended in the northern hemisphere to Shanghai (31° 14′ N.), Binninag (29° 36′ N. 80° E.), the China Seas, India, Arabia, the Canary Islands, the Gulf of Mexico, Virginia, U.S. (occasional), Yucatan (20° N. to 23° 25′ N. 33° 15′ W.), Florida, Honolulu, and occasionally and feebly to southern England. In the southern hemisphere they continued brilliant in Australia, Tasmania, New Zealand, the southern Indian Ocean, the Transvaal, and the Cape, at Carrizal (north of Valparaiso), Buenos Ayres, and a large part of the Atlantic and Pacific.

On October the 14th they reached Santa Barbara (California), at about 34° N. 120° W.; and on October 15th, Montgomery (Alabama, U.S.A.), at about 32° 20′ N. 86° 20′ W.; and Lisbon and Nice, at about 39° N. and 43° 42′ N. respectively.

On October 19th, Yuma (33° N. 115° W.) and Oakwood (California), were reached; and some bright cloud effects were at this time observed in Surrey. In the Kangra Valley, at 32° N., an aurora-like glow was seen on October 24th. At the end of October many places in the southern and eastern States of the Union were reached; and at Charlotte (N. Carolina), at about 35° N. 80° W., the sky was like fire on October 30th. During October the glows were seen continuously in the Pacific between New Hanover and Honolulu.*

Many sporadic glows were observed from this date in the United States, and a little later in Europe; and to these belong the magnificent illuminations on November 9th, in England. The main body of sky-haze seems to have reached about 38° N. on November 15th; and on November 23rd, the northern States and Canada, to about 45° N., and British Columbia, to about 50° N., were affected.

On November 24th the glows extended as far north as north-west Iceland; but there is no mention of them in Norway or Sweden, or any other high latitude. They

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* 'Nature,' vol. xxix. (1884), p. 259.

were observed only partially in England and Ireland. On November 25th, however, they covered a large part of these islands, and were seen sporadically in France and Italy. In parts of Scotland there was a fine display on the 25th. On November 26th the whole of England, a great part of France and Italy, Denmark, and parts of Germany, especially south and west, were affected, and they continued magnificent in Canada and parts of the United States. Professor RICCÒ mentions that though the glows were seen in Italy from November 26th, they did not become very striking till the first days of December, that is, four days later than in England. On November 27th, glows were seen in south-east Iceland, parts of Denmark, and many places in Germany. On November 28th they extended far south and east, including Berlin, Constantinople, Angora, the Crimea (end of November), Lesina, and Brindisi, nearly the whole of Germany, and Switzerland. On November 29th, to Algiers, Madrid, and Carinthia. On November 30th, to Stockholm and Christiania, and to Druskeniki, in Russia. On December 1st the whole of western Europe had most brilliant displays; and they seem to have reached to Grauheim, 61° 6′ N. 8° 35′ E., and Upsala, about 60° N. 18° E., and Malta and Athens, about the same date. In the United States they continued, and were brilliantly renewed at Honolulu early in December. At Mauritius they continued. During November the glows were seen continuously in the Pacific between the Marshall Islands and Honolulu.* On December 2nd they reached as far north as Stenkjeer, 64° 1′ N. 11° 25′ E., and seem to have spread over Russia in the beginning of December. Early in December they were very strong in Europe, North America, the north Atlantic, part of the Pacific, India, Australia, and New Zealand. On December 4th the glow reached Crete, and was described by telegram as "aurora." On December 7th the glow was intense in North America, Spain, and Switzerland, but much fainter in Surrey. On December 11th the arrival of a brilliant after-glow was telegraphed from Kiachta, Siberia, in 50° N. 107° E.; and on December 16th, in the Crimea, it was taken for "aurora." From December 18th to 25th the glows were strong at Vadsö, 70° 4′ N. 29° 45′ E. On December 29th a green sun and red glow is reported from Hankow, in 30° N. 120° E.

From the end of December it becomes impossible to trace the march of the glows, for, every part of the globe seems to have been by that time covered, and though many alternations in intensity occurred everywhere, no revolution period can be distinguished; and on the whole there was a steady decline, both in duration and in brilliancy, in the first months of 1884.

In April, 1884, there was not, in south-eastern England, the slightest illumination of the sky after sunset beyond the ordinary twilight. Recurrences of a moderate after-glow on a few days in the summer and autumn were, however, reported from several parts of the country.

In South Africa, glows continued to occur in May; and in Australia they had apparently not altogether ceased in July. In the Atlantic several were reported in

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* 'Nature,' vol. xxix. (1884), p. 259.

March, 1884, by Mr. DOVE, on the *Superb*. At Rangoon, which had hitherto been little affected, glows were seen from January 22nd, 1884. At Adelaide, Australia, they were bright on February 1st, 3rd, 6th, 8th, 11th, 17th, 18th, 24th, 26th, 27th, 29th. At Honolulu there was some reappearance of the glows in May, 1884, and again on August 19th, 1884.

At Berlin there was an after-glow on June 26th, and at Cartagena on July 9th, 15th, and 20th. At or near Huntingdon, England, Prof. A. S. HERSCHEL saw the white glare and after-glow on September 20th, 1884. In October, 1884, several after-glows were reported in England. At the end of March, and in April, July, September, and October, after-glows were seen at Cambridge, Mass., U.S.A., and on October 13th, 1884, at Vancouver's Island.

Even in 1885, Professor RIGGENBACH detected twilight phenomena which he referred to a prolongation of the peculiar condition in the upper air which produced the displays of 1883 and 1884. We cannot do better than refer to the full details of observations given in his pamphlet referred to in Section IV., p. 362.

The Table appended to this Section, and giving the velocity of the smoke-stream round the world, shows that a complete circuit was made within the tropics in about thirteen days. The same cyclical period appears from the dates of recurrence in a large number of instances. Thus, the blue sun was at its maximum in Ceylon on September 9th, 10th, 11th, 12th, 22nd, 23rd, 24th; the interval from August 27th to September 9th is thirteen days, and from September 9th to 22nd also thirteen days.

The interval between the appearance of an obscured sun at the Seychelles, on August 28th, and of a green sun and moon on September 11th, in the Red Sea, is fourteen days, and between this and the green sun on September 24th, at Duem, thirteen days.

The interval between the haze and white sun of September 1st, in 9° S. 28° W., and the similar haze in 14° N. 26° 42′ W., on September 13th, is thirteen days; and in the eight days from the 5th to the 13th the Captain of the *Queen of Cambria* reports nothing unusual. He remarked, on September 13th, that the haze was like that first seen September 1st and last September 5th.

The blue sun was seen at Trinidad on September 2nd, and at Barbadoes on September 15th, an interval of thirteen days.

The interval between September 1st, when the sun was blue in the morning in 10° 40′ N. 26° 30′ W., and September 14th, when the sun set green in 11°·25 N. 19°·9 W., is thirteen and a half days.

The interval between the green sun of September 14th, in 11°·25 N. 19°·9 W. and 14° 36′ N. 27° 2′ W., and the blue sun in 9° S. 35° W. on September 28th, is fourteen days.

The interval between the first green sun at 160° W., on September 4th, and the appearance of a green sun and moon on September 17th, in 12° 12′ N. 146° 7′ W., is thirteen days.

The green sun was first seen at Honolulu on September 5th, and again in the neighbourhood of the Sandwich Islands on September 18th and 19th, an interval of thirteen days.

A red sunset was first seen at Mauritius on August 27th, and there was a decided increase in brilliancy on September 22nd, an interval of 2 × 13, or twenty-six days.

The maxima of glows at Muscat were on September 13th, 28th; October 12th, 27th, intervals of fifteen, fourteen, and fifteen days.

The interval between the first appearance of an after-glow at Chelsea on September 8th, and its re-appearance on September 20th, is twelve days. (The interval might possibly have been nearer thirteen days if the equatorial stream in the second circuit had not extended much further north than in the first.)

In October there is no sign of a distinct periodic recurrence of haze or of glows.

SUMMARY OF PART IV., SECTION III. (A).

The dates in the general list leave no doubt that, on the whole, the tendency of the matter causing the twilight phenomena was to spread northwards and southwards as well as westwards during the rapid circuit of the blue sun matter from east to west within the tropics. The dates for India and the United States show this most distinctly. Excluding sporadic glows, due probably to small broken-off masses of the great cloud of matter, we find the northern limit near the end of the first circuit to have been about 22° N. at Honolulu, or 28° north of Krakatoa, and the southern limit about 33° S. at Santiago, or 27° south of Krakatoa. Wellington, New Zealand, at 41° S., cannot be taken as the southern limit; for Australia does not seem to have been affected so early as September 9th. In none of those places which were on the extreme borders of the main stream, or beyond it, were the glows regular and continuous from the date of the first appearance. Nor could they be expected to show continuity, when we have evidence that the cloud causing the rayless sun passed over most places in the tropics within three or four days. Towards the end of the first circuit, that is, in the Pacific, the amount of matter left behind after the passage of the main cloud seems to have been greater than in the Atlantic near the Equator, where the sky in most parts presented no remarkable appearance after September 5th, until the arrival of the cloud on its second circuit.

At the end of the second circuit, about September 22nd, the glows may be roughly stated to have extended from between 20° and 30° N., to between 30° and 40° S., but their distribution was not regular within these limits.

While the movement westwards may be presumed to have continued after this date, there can be no doubt that a gradual extension northwards and southwards greatly widened the area over which the red twilights were seen during the next fortnight. They were conspicuous at several places between 20° and 36° N., and southwards as far as 27° S., in many different longitudes. Throughout October the Gulf of Mexico and corresponding latitudes were under the full effect of the glows. On October 7th Nashville, about 36° N., and Buenos Ayres, at 34° 39′ S., had brilliant sunsets; and at Binninag, India, 29° 30′ N. 80° E., there was a fiery after-glow till 7.20 p.m. At the Canary Isles, 28° N., the glows were conspicuous. At Shanghai, or not far south of it, they were observed by pilots.

By October 15th the glows had extended still further north; in the United States they had reached 34° 27′ N., in Europe partially to 43° 42′ N., in Arabia to an unknown latitude, and in India to Umballa, 30° N.

By the end of October the glows had spread over the southern, and part of the eastern States of North America, while Australia, Tasmania, New Zealand, South Africa, and Chili, were under their full effect.

Up to about November 23rd glows seen north of about 32° to 36° N. were for the most part detached or sporadic.

But, about November 23rd, a very remarkable movement took place, in such a manner that the direction in which the main stratum progressed is not clear, in spite of a large collection of dates. Western Canada, British Columbia, California, and north-west Iceland, seem to have been first affected, and then in succession, England, Denmark, France, Italy, Germany, Spain, Algeria, Austria, Turkey, Russia, eastern Siberia, and northern China. To distinguish sporadic from continuous glows is no easy matter. But a general view inclines us to regard this later movement as taking place from west to east. An exact course cannot be determined owing to the inequality in density and irregularity of outline of the great cloud. Excluding occasional displays, the glows were seen in the north-western parts of Europe about a week before they drew attention in the east and south-east. England, as a whole, was affected before Denmark as a whole, Denmark before northern Russia, northern Russia before Kiachta. North Italy and Lisbon, parts of France and Germany, were affected on the 26th, south-east Iceland, and a large part of western and central Europe, on the 27th, part of eastern Europe on the 28th, southern Italy and Greece about December 1st.

Over the northern part of North America the direction of movement does not appear, for the glows were seen about November 23rd in both east and west, and we can only infer that they were spreading quickly from the south, where they had long been sporadically noticed. San Francisco, New Westminster, and Oregon and London, Ontario, report them as beginning about the same time. On November 27th they were general in the States.

Perhaps the most probable supposition is that the main cloud both in America and in Europe was moving from nearly west to east; at all events, in the northern parts, with large offshoots extending from south or south-west to north or north-east.

On the assumption of the northern limit having been continuous in the same latitude, it would be difficult to account for the eastern States having had glows at the same time as the western (while in Europe the east was later by about a week), and for England having been the first of European countries to enjoy them in their full splendour.

The movement of the earlier detached clouds, which reached parts of the northern States, England, and Russia, between November 8th and 11th, is equally uncertain. Their structure in England, however, indicated a movement from a point between W. and S.

The structure of the main cloud indicated a motion from S.S.W. to N.N.E., or an initial motion from south to north, gaining an eastward drift. Observation showed, if anything, a slow motion from west to east.

A survey of the course of the phenomena of the sunset glows leads us to infer that within the tropics the matter causing them moved at about 73 miles an hour from east to west, and gradually spread southwards and northwards, becoming thinner and more diffused, so that by the end of a period of six weeks, viz., the 8th of October, nearly the whole space included between 30° N. and 45° S. had been subject to the phenomena; and that the motion from east to west became arrested as the matter travelled northwards and southwards. Further north and south than about 30° or 35°, it seems probable that the motion was from south-west and west in the northern hemisphere and from north-west and west in the southern hemisphere The rapidity of propagation to South Africa and Japan was so great that we can hardly doubt the prevalence at the time of a direct upper current in each direction at a level below that of the great current which carried the dust from east to west at the velocity above mentioned. The march of the glows over N. America and Europe at the end of November appears to have been part of a movement of the hazy stratum from over the mid-Pacific and mid-Atlantic Oceans respectively, but we have no data for affirming that the glows receded from those vast areas at the corresponding time. From Honolulu, we have a report of an increase in brilliancy on November 25th,* and of a prevalence of the glow between Honolulu and New Hanover continuously during September, October, and November; while the *Papa*, sailing from Apia (Samoan Islands), had nothing of the kind during October and November.

F. A. Rollo Russell.

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* 'Nature,' January 17, 1884.

SECTION III. (B).

THE CONNECTION BETWEEN THE PROPAGATION OF THE SKY HAZE WITH ITS ACCOMPANYING OPTICAL PHENOMENA, AND THE GENERAL CIRCULATION OF THE ATMOSPHERE.

By Mr. E. DOUGLAS ARCHIBALD.

Regarding the prevailing westward extension of the phenomena after August 26th, 1883, at first along a relatively narrow zone on each side of the Equator, it seems natural for the smoke of a volcano, situated like Krakatoa, 6 degrees south of the Equator, to drift in the direction of the prevailing wind of that locality, west rather than east; and though we have little direct evidence that the upper atmosphere near the Equator moves generally in the same direction as the lower trade winds, there is evidence that both in the minor and in the major eruptions of Krakatoa in 1883 the volcanic emissions (including both the ashes and the finest dust) travelled further in a westerly than in an easterly direction, and that the air currents generally tended in this direction. Thus Mr. VERBEEK, in 'Krakatau,' p. 11, states that in the preliminary eruptions of May 21st to 23rd, 1883, the sounds were propagated much further (up to 835 kilometres, or 519 miles) in a westerly direction, than towards the east, where they did not appear to extend beyond Poerwakarta, 225 kilometres (140 miles) from Krakatoa.

Again, at 7 p.m. on May 23rd, the Dutch steamer *Conrad*, when close to Krakatoa, reports the following remarkable fact. After mention is made of great inconvenience being felt from a thick rain of ashes and from sulphur vapour, we are told that "à quelque distance on voyait la fumée noire coupée net, comme si elle était arrêtée contre un mur par la mousson de l'Est, tandis qu'à l'Ouest la cendre s'étendait à perte de vue."*

Other facts mentioned by Mr. VERBEEK support the same conclusion; thus the falls of ashes on the *Madura* and at Teloek Betoeng, referred to already, both being to the west of Krakatoa, contrast strongly with the fact that during these eruptions there is a total absence of any record of the fall of dust or ashes at the nearest places to the east in Java.

At Vlakke Hoek, the south-westernmost point of Sumatra, 62 English miles due west of Krakatoa, "a rain of ashes commenced to fall on the morning of May 20th, and continued until the afternoon of the 23rd, the moment when the wind turned from the east to the north."

Moreover, Captain FERZENAAR, who furnished a report to Mr. VERBEEK, after visiting the island and its vicinity on August 11th, said that during all the eruptions from May 20th up to that date, by which time the three principal craters were in action, the ashes had been blown chiefly in a north-westerly direction.

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* 'Krakatau,' p. 15.

During the major eruptions of August 26th and 27th, a similar dominance of westerly over easterly motion is still more noticeable.

Thus, while at places like Buitenzorg and Batavia, to the east of Krakatoa, the darkness was either never complete or lasted only two or three hours, in districts at much greater distances to the west, in Sumatra, the darkness appears to have been more extensive, more intense, and of much longer duration.

As the distribution of the ashes was clearly like the darkness, a direct function of the direction in which the ejecta were mainly carried, we are prepared to find, as was actually the case, that their extent, duration, and thickness were much greater towards the west than towards the east of Krakatoa.

This is plainly shown in the accompanying Tables, I. and II., in which the duration of these phenomena at the principal places east and west of Krakatoa, in its vicinity are compared, together with their distances from the volcano; the data, with the exception of the distances, being taken from Mr. VERBEEK's 'Krakatau.'

The data for the exact durations of both the ash falls and the darkness are in some cases wanting, and the latter is given for only the day in Table II., in one or two cases, when by comparison with the shorter definite cases in Table I., it probably lasted as long as the corresponding ash fall, or through the night. But notwithstanding these lacunae, it is evident that on the west side of the volcano, at a mean distance nearly double of that on the east, the duration of the ash fall was nearly four times as great, and that of the darkness, in any case, more than double.

TABLE I.

Towns or Districts E. of Krakatoa.

Name and direction from Krakatoa.	Distance from Krakatoa.	Duration of Darkness and Ashes, and Remarks.					
	English miles.	Ashes.		hours.	Darkness.		hours.
		Began.	Ended.		Began.	Ended.	
E. Anjer	31	August 26, 9 p.m.	?	12	August 27, morning.	August 27, evening.	12 ?
S.E. Panimbang ..	37	August 27, morning.	?	?	August 27	August 28; morning.	12 ?
E. Serang	48	August 27, morning.	11 p.m.	17	All	day.	12
E. Tangerang	79	August 27, 10 a.m.	4½ p.m.	6½	August 27, 10 a.m.	4½ p.m.	6½
E. Batavia	94	August 27, 11 p.m.	2 p.m.	3	August 27, 10.30 a.m.	2 p.m.	3½
S. E. Buitenzorg ..	100	August 27, 11.20 a.m.	3 p.m.	3⅔	August 27, 10.30 a.m.	1 p.m.	2½
Means	65	—	—	$8\frac{13}{30}$	—	—	$8\frac{1}{12}$

TABLE II.

Towns or Districts W. of Krakatoa.

Name and direction from Krakatoa.	Distance from Krakatoa.	Duration of Darkness and Ashes, and Remarks.					
	English miles.	Ashes.		hours.	Darkness.		hours.
		Began.	Ended.		Began.	Ended.	
N. and by W. Teloek Betoeng.	49	August 25, evening.	August 28, 3 a.m.	57	All day (?) 27th; at 10.30, 27th, l'obscurité plus noire que la plus noire nuit.		12 ?
W. by N. Blimbing ..	60	August 26, 6.30 p.m.	August 27, 10.30 p.m.	28	All day.		12
N.W. Semanka ..	72	August 26, 5.30 p.m.	?	24 ?	?		12
N.W. Kroë	133	August 27, 3 a.m.	August 28, 11 a.m.	32	August 27, 10 a.m.	August 28, 8 a.m.	22
N.W. Bencoolen ..	276	August 27, 12 a.m.	August 28, 11 a.m.	23	August 27, 10 a.m.	?	?
W. by S. Ship *Berbice*..	60	August 26, 6 p.m.	? same as Blimbing.	28 ?	August 27, all day.	August 28, 8 a.m.	22
Means	108	—	—	32	—	—	16

Other incidental remarks show that the intensity, as well as the duration both of the ashfall and of the darkness, was greater on the western side. Thus, at Teloek Betoeng, at 10.30 a.m. on August 27th, the darkness is described as "blacker than the blackest night," and at Kroë the obscurity was "deeper than that of night."

An inspection of the ash-map accompanying Mr. Verbeek's Report shows the same preponderance of ashes on the western side. From the absence of land to the west of Krakatoa it would appear from the map that the ashes had been carried mainly to the north-westward and south-westward, reaching as far as Singapore and Benkalis in the former case, and Keeling Island in the latter; but this may not have been so much the case as the chart would lead us to suppose; for, between these points the area is mostly sea; and while the actual limit of the ashes on the west coast of Sumatra was Moeko Moeko, 600 kilometres from Krakatoa, in several places up to a distance of 400 kilometres the falls reached a thickness of 20 mm. On the other hand, in districts to the north-east and east, such a thickness was not observed beyond 100 kilometres from the volcano. We may, therefore, conclude that between Moeko Moeko, and Keeling Island, the ashes fell much further in a westerly direction than appears from the arbitrary line joining the two on the map.

The same conclusion follows from an inspection of his map which represents the district over which the finer dust fell on ships traversing the Indian Ocean between August 27th and 30th. The form of the area is elliptical, with its major axis in a line due west from Krakatoa, which occupies its eastern extremity; the major axis being about 30°, or 2000 miles, in length, and the minor 700 miles north and south.*

Further evidence may be considered to be afforded by the distances at which sounds were heard which, as shown by General STRACHEY's map, Plate XVI., was nearly 50 per cent. greater towards the W.S.W. than in any other direction.

It may be remarked, that in the vicinity of the volcano during the eruption, the wind at the surface at first blew mostly from the south and west, changing afterwards to south-east, and in parts, especially in the neighbourhood of Teloek Betoeng, it blew temporarily with hurricane force about the time of the greatest eruption on the 27th.† This was, therefore, in all probability, an indraft caused by the rapid ascent of the gases and materials ejected from the volcano.

On the whole, therefore, we have abundant evidence that at lofty altitudes over a wide area surrounding the volcano, the atmosphere had a considerable westerly motion, during May and August, and that the majority of the materials ejected from Krakatoa during the grand eruptions of August 26th and 27th, like those during the minor eruptions in May, were from the *first* mainly carried in this direction.

That this westerly motion was much swifter in those upper strata of the atmosphere in which the finest dust remained suspended, is plain from the high velocity of translation of the optical appearances westward round the world; but such velocities as 70 to 75 miles an hour are by no means excessive even for cirrus clouds at much lower elevations; while in the present case, if, as we must suppose, the dust which fell on ships in the Indian Ocean had been transported for the most part by lower currents, the velocity above seems by no means out of proportion to that indicated by the dates of the falls on vessels for some considerable distances to the westward of Krakatoa. Thus, taking some of the best determined observations up to August 29th, we get the following rates for the velocity with which the dust travelled from Krakatoa, assuming it to have started at midnight on August 26th, which being 10 hours before the grand explosion on August 27th, and 10 hours after the first noticeable explosion on August 26th, is taken as the average epoch of commencement.

Only the rates to ships at considerable distances from Krakatoa have been taken, as the nearer ones might have experienced falls from minor eruptions before August 26th which escaped notice.

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* See also Plate XXXVI. in this volume.

† Several trees were uprooted by the force of the wind on the island of Sebockoe.—'Krakatau,' p. 488.

Date.	Hour. (Local time.)	Ship.*	Distance in English Miles from Krakatoa.	Mean Velocity of Ash Stream in Miles per Hour.
Aug. 28.	5.30 a.m.	*Salazic.*	888	30
Aug. 28.	2 p.m.	*Simla.*	1,190	31
Aug. 28.	0 a.m.	*Brani.*	968	40
Aug. 28.	5 a.m.	*Arabella.*	1,141	39
Aug. 28.	2 a.m.	*Castleton.*	830	32
Aug. 28.	0 a.m.	*Barbarossa.*	844	35
Aug. 29.	Noon.	*British Empire.*	1,787	29
		Means	1,093	34

NOTE.—These are the distances at noon on the day mentioned in the date column. None of the vessels, however, were steamers, and in no case will the distance given differ more than a few miles from the actual distance at the time given in the hour column.

If, now, we suppose that the mean height at which the heavier dust floated, which thus fell on the ships was 10,000 feet (which is a fair allowance, considering that during the last part of its äerial journey it was travelling with only the moderate speed of the air near the surface),† by an application of the formula

$$\frac{V}{v} = \sqrt[4]{\frac{H}{h}}\,.$$

(where V v, H h, are the velocities and corresponding heights at two upper and lower points in the atmosphere) which I had found ‡ to agree best with Dr. VETTIN's observations of the velocities of different cloud-strata up to 25,000 feet, as well as with his own anemometrical observations in the free atmosphere between the ground and 1800 feet above it, we shall find that the velocity of 36 miles an hour at 10,000 feet would be increased to 60 miles an hour at 100,000 feet above the sea, and (see Section IV., p. 340) to 64·5 miles an hour at 130,000 feet, which brings it nearly to the amount (73·5 miles) that has been calculated from observation.

We have preliminary evidence of the initial westward trend of the ejected material from Krakatoa on August 26th and 27th for some considerable distance from the volcano, and at a rate nearly equivalent to that required by the succession of dates of the first appearances of the coloured suns, cloud-haze, and twilight glows.

We have no independent observational proof that such currents would be continued right round the globe, either temporarily or continuously, but there seems

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* These ships were all west of Krakatoa; their mean latitude was 5° 24′ S., that of Krakatoa being 6° 8′ S.

† The direction of the lower wind over the neighbouring sea area during the eruption was between S.E. and N.E.—'Krakatau,' p. 149.

‡ 'Nature,' vol. xxxiii. (1886), p. 95. N.B.—This formula applies better to the higher levels than to those near the surface, where the increase is more rapid.

to be a recent theoretical investigation by Dr. WERNER SIEMENS on "the conservation of energy in the earth's atmosphere," referred to by Professor KIESSLING in his paper, "Ueber die Bewegung des Krakatau-Rauches in September, 1883,"[*] in which he shows that under the Equator the air which experiences no friction at all should acquire a velocity in a direction from east to west of about 142 miles an hour.

If this hypothesis be confirmed by future observation, it may possibly help to account for the continued westerly projection of the main mass of material, in the present case, at the rate demanded by the dates of the successive first appearances of the optical phenomena.

The observed velocities of cirrus clouds, often amounting, as Rev. W. CLEMENT LEY has shown, to over 120 miles an hour, and the general results of Dr. VETTIN'S observations at Berlin, recently published,[†] in which the upper cirrus in winter, at a height of only 23,600 feet, moves at an average rate of 44·5 miles, favour the notion that in a region four times the latter height a temporary velocity of from 70 to 80 miles would not be anything extraordinary. The only remarkable point about such a current as we must assume to have existed on the present occasion, is the constancy of the motion over so large a tract of the earth's surface for so long a period, and of this we have hitherto had no evidence which can be held to be distinctly corroborative. At the same time there does not appear to be anything arising out of the theory, or observation of the general atmospheric circulation, to forbid the existence of so constant a current at 100,000 feet or more over the equatorial zone. The anti-trade currents do not probably reach this great altitude; if they do, they cannot commence to have an easterly trend very near the Equator, for the east to west component of the lower trades can disappear at only the north and south borders of the ascending trades, where the meridional motion due to the equatorial bulge commences, and where the deflecting force due to the earth's rotation, viz., $2\,n\,v \sin\theta$—

(where n = angular velocity of the earth's rotation,
θ = latitude,
and v = velocity of the air)—

has some *appreciable* value.

In the central portion of the bulge, between these two limits, there is no reason why the air should not move in the same direction as the lower trades, and at an enhanced velocity due to the lessened friction.[‡]

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[*] 'Sitzungsberichte der Königlichen Preussischen Akademie der Wissenschaften zu Berlin,' vol. xxx. (1886), p. 529.

[†] "Die Luftströmungen über Berlin in den vier Jahreszeiten." 'Met. Zeitschrift,' August, 1886.

[‡] This point is dwelt upon more fully in Section VII., p. 426.

The number of meteorological observatories in the neighbourhood of the Equator is still very limited in comparison with its large area, and observations of the movements of the upper clouds have been made in far too small a number to form a trustworthy basis for any conclusions. The Hon. RALPH ABERCROMBY, in his two recent voyages round the world, in which he crossed the Equator several times, noticed the movement of the upper clouds to be generally from some easterly point;[*] but to establish the fact that this is always the case would obviously necessitate prolonged observation at suitable spots in all parts of this region.

It may be noticed that, in the Pacific, the zone of equatorial calms reaches its widest area during August, the month of the great eruption of Krakatoa, varying, according to KERHALLET,[†] from 135 miles in February to 840 in August.

Another peculiarity in the transmission of the lighter ejecta in the present case which negatively favours the existence of the east to west current over the Equator, is the occurrence of limited transmissions in the direction of the anti-trade systems on each side.

If the anti-trade systems were separated by only a narrow belt from one another, we should have expected to find most of the material transported towards Japan on the one hand, and towards Australia on the other, and hardly any carried west.

The facts, on the contrary, show that only a portion of the material was entrapped, as it were, by the ordinary upper return trades; a narrow line of coloured suns and glows appearing in turn at Labuan Island, Fisher Island, and Tokio, &c., on the one side in a N.N.E. direction, and dust falling near the coast of Australia on the other side[‡] in a S.S.E. direction. Also, if we connect the appearances seen at the Cape and Natal with those at Mauritius, it appears that, Krakatoa being situated 6° south of the Equator, some of the material carried by the main upper current subsequently got caught by some subsidiary upper current, which carried it possibly in a parabolic curve as far south as the Cape.

At all events, the stream towards Japan was typically anti-trade in character, and the fact that no similar transmissions took place over India or Burmah shows the transmission in that direction to have been of limited width. The velocity was about half that of the grand stream which was carried round the Equator from east to west.

The following table of velocities of the principal and subsidiary streams by different computers is inserted for comparison:—

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[*] 'Nature,' May 26th, 1887. The Hon. RALPH ABERCROMBY found the highest cirrus coming from the east over the north-west monsoon in two different years; and also, on one occasion, over the south-west monsoon in the Gulf of Guinea.

[†] 'Considerations Générales sur l'ocean Pacifique.' RECLUS, 'The Earth and the Ocean,' vol. ii.

[‡] On board the *Meda*.

—	Velocity in Miles per Hour.		
	Mr. Russell.	Prof. Kiessling.	Mr. Verbeek.
General stream round Equator east to west from Krakatoa.	76	84·9	82·9*
	Mr. Archibald.		
Stream towards Japan	39·3	44·7	50†
Stream towards the Cape..	—	78	—

On the whole, therefore, it may be said that the facts relating to the general westward propagation of the heavier dust, borne by the ordinary upper wind which blows from east to west in the Javan area at more than 6,000 feet above sea level, as well as those relating to the general and special transmission of the finer dust, accord well with the theory that along the Equator, and for a few degrees on each side, the principal motion of the air (except near the surface itself) is constantly from east to west, and that while the heavier portions of the dust travelling in the lower atmosphere were dropped, for the most part, to the west of Krakatoa, the lighter portions remained suspended in the higher regions, where the motion is more rapid and perhaps more constant, and were carried right round the Equator, certainly twice, and perhaps continuously.

The Rev. S. E. Bishop, of Honolulu, in his original pamphlet on the Equatorial Smoke-stream, and in a recent communication,‡ accounts for the due westward propagation of the main stream from Krakatoa, by supposing that the finer ashes were ejected to a height of 100 miles, whence, descending by gravitation, and having an initial westward lag, they derived a powerful initial impulse which drove them westwards independently of any current existing at an altitude of 30 miles or more.

Assuming the material to have been shot up to so enormous an elevation, and neglecting friction for the moment, an initial lag westwards of about 26 miles an hour would be generated ; but even so, and granting that the material slid down an inclined plane with considerable velocity, as the author assumes, would it necessarily continue this velocity after arriving at lower levels, or anywhere where the air possessed sufficient viscosity to hold it in suspension ? According to Professor Stokes's formula as applied to the upper regions of the atmosphere, it appears quite impossible for the materials, whether dust or gases, to perform this feat, and we, therefore, seem obliged to account or this westward translation only by the hypothesis, already suggested, of a current existing at this altitude of the direction demanded by the motion.

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* If starting point is made August 26, 2 p.m., velocity = 78·2.

† From Yokohama alone.

‡ 'American Meteorological Journal,' July to August, 1886.

Moreover, Mr. BISHOP gives no reasons in favour of the material having reached this enormous height, other than the extreme violence of the eruption, and the fact that some of the heavier materials were shot obliquely to a distance of from 30 to 70 miles from Krakatoa.

Mr. VERBEEK, in his 'Krakatau,' pp. 127-9, discusses this latter point; and finding the evidence on which the second distance depends very uncertain, estimates the maximum height of projection from the former distance, as is mentioned in Section IV., p. 379, at about 164,000 feet, or 31 miles—a very different figure from Mr. BISHOP'S 100 miles.

Again, Mr. BISHOP assumes* the stream to stop at the Caroline Islands on its first journey; whereas we find strong evidence of its prolongation, not only for one, but two complete circuits of the globe; the dates of the first appearances in India and other regions excluded by their latitude from participation in the effects of the stream, as it first issued from the Sunda area in a narrow belt, agreeing with the hypothesis of a second revolution of the stream; and not with the more artificial theory put forward by Mr. BISHOP, of a much slower diffusion of the main body of material by atmospheric currents, which, to make the dates concordant, must be assumed to have travelled towards India at the rate of 6 miles an hour, and to the Soudan at 8 miles an hour, a difference of 33 per cent. in excess of the former.

E. DOUGLAS ARCHIBALD.

SECTION III. (c).

SPREAD OF THE PHENOMENA ROUND THE WORLD, WITH MAPS ILLUSTRATIVE THEREOF.

By the Hon. ROLLO RUSSELL.

The accompanying map, Plate XXXV., gives the dates and sites of as many of the phenomena as could be conveniently recorded upon it. The series of small maps on Plate XXXVI. show, as far as may be gathered from the scattered observations in our possession, the area affected by unusual phenomena in successive periods from August 26th to the end of November. The dotted lines bounding the shaded portions indicate the approximate northern and southern boundaries of the elevated haze which gave rise to the conspicuous changes in the colour of the sun or sky. A continuous dark line shows a better ascertained limit, and an absence of bounding lines, as in IV. and V., signifies a total failure of available data from which any limit could be drawn.

Isolated observations, such as the two in Ceylon during the week August 27th to September 4th, and the appearances seen at the end of August in a narrow stream from Java to Japan, are omitted in these maps. In No. I. the dotted line inclosing

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* 'American Met. Journal,' July, 1886, p. 125.

DISTRIBUTION
OF
OPTICAL PHENOMENA
in August and September, 1883.

EXPLANATION.

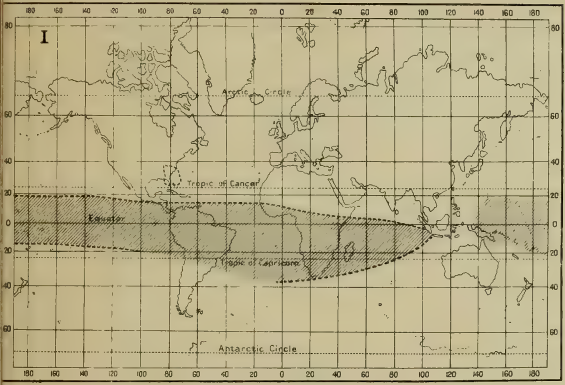
Plain figures = Blue, green, or otherwise coloured sun.
□ = Red or otherwise coloured twilight glow
○ = Lofty haze or appearance of cirro stratus
△ = Fall of dust or ashes

The figures indicate the dates of the phenomena, those from 26 to 31 inclusive refer to August, 1883, and those from 1 to 25 inclusive refer to September of the same year.

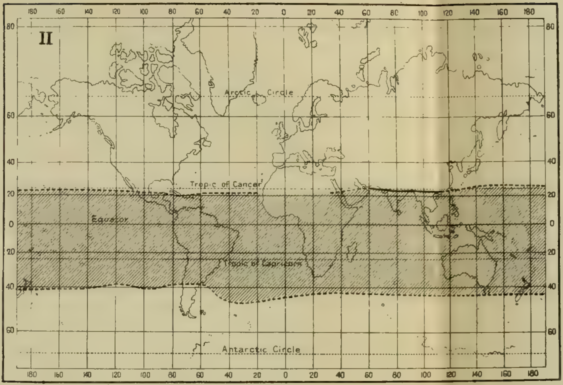
N.B._ In order to avoid crowding, many observations have been omitted, especially in the Indian Ocean.

Mallry & Sons. Lith

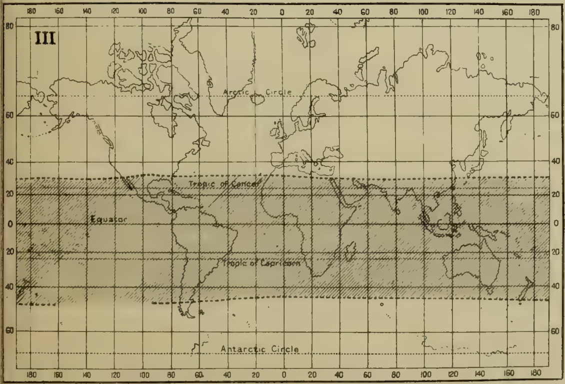
APPROXIMATE DISTRIBUTION OF SKY PHENOMENA BETWEEN AUG. 26 AND SEPT. 7, 1883.



APPROXIMATE DISTRIBUTION OF SKY PHENOMENA BETWEEN SEPT. 9 AND SEPT. 22, 1883.

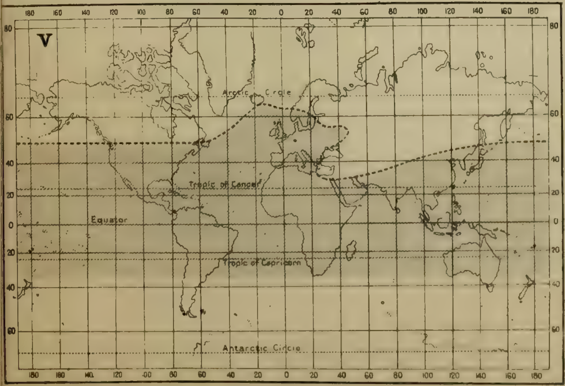


APPROXIMATE DISTRIBUTION OF SKY PHENOMENA FROM SEPT. 22 TO OCT. 10., 1883.



APPROXIMATE NORTHERN LIMIT OF THE MAIN SKY PHENOMENA FROM OCT. 10 TO 31, 1883.
No data exist for the indication of a Southern limit.

APPROXIMATE NORTHERN LIMIT OF THE MAIN SKY PHENOMENA AT THE END OF NOVEMBER 1883.



PROGRESS OF THE MAIN SKY PHENOMENA FROM AUG. 26 (EVENING) TO SEPT. 9 (EASTERN TIME). 1883.

Day & Son, Lith.

Florida shows the rather extensive area over which red twilights were seen from September 5th to 9th, including probably the West Indian Islands, from which observations are wanting. In No. VI. the front of the cloud is shown, on successive days from August 26th to September 9th, by dotted lines, the only complete blanks occurring during the passage across Central Africa on August 29th, and between 170° E. and 135° E. on September 8th (Eastern time).

SPREAD OF BLUE SUN, RED GLOW, AND SKY HAZE, DURING THE FOUR WEEKS FOLLOWING AUGUST 26TH, 2 P.M., KRAKATOA TIME.

B. = Blue, green, silvery, or obscured sun. H. = A lofty haze or appearance of extensive cirro-stratus. R. = A red glow before sunrise or after sunset, or a white or peculiar leaden sky, morning or evening.

—	Distance from Krakatoa, in English Miles.	Local time of their appearance.*	Interval to nearest Hour.	Rate per hour to nearest Mile.
Krakatoa to Kokkulai, Ceylon, B.	1,980	4 p.m., ? 27th Aug.	28	71
,, Mullaittivu, Ceylon, B.	2,009	4 p.m., 27th ,,	28	72
,, ,, ,, H.	2,009	6 a.m., 27th ,,	18 †	[112]
,, Tokio, Japan, R.	3,644	6 p.m., 29th ,,	74	49
,, ,, ,, B.	3,644	Noon, 30th ,,	92	40
,, Seychelles, H.	3,442	6 a.m., ? 27th ,,	19 †	[181]
,, ,, B.	3,442	6 a.m., 28th ,,	43	80
,, ,, R.	3,442	6 p.m., 27th ,,	31 †	[111]
,, Mauritius, R.	3,353	6 p.m., 28th ,,	55	61
,, Réunion, R.	3,495	6 p.m., 27th ,,	31 †	[113]
,, Natal, R.	5,084	6 p.m., 28th ,,	57	89
,, Cape Coast Castle, B.H.	7,353	6 a.m., 1st Sept.	143	51
,, 2° S. 5° E., H.	6,924	6 a.m., 31st Aug.	119	58
,, St. Helena, R.	7,486	4 a.m., 30th ,,	93	80
,, 10° N. 26° W., H.	9,102	6 p.m., 30th ,,	109	84
,, 10° 40′ N. 26° 30′ W., B.	9,138	6 a.m., 1st Sept.	145	63
,, 12° 42′ S. 27° 18′ W., B.	8,948	5 p.m., 1st ,,	156	57
,, *Corona*, 2° 30′ S. 20° W., R.	8,635	6 p.m., 30th Aug.	108	80
,, ,, 1° 19′ S. 21° W., B.	8,708	8 a.m., 31st ,,	122	71
,, *Queen of Cambria*, 9° S. 28° W., B.	9,067	8 a.m., 1st Sept.	147	62
,, *Olbers*, 3° 5′ N. 27° 6′ W., R.	9,161	6 p.m., 31st Aug.	133	69
,, *British Envoy*, 13° 33′ N. 31° 29′ W., R.	9,464	6 a.m., 31st ,,	121	78
,, Maranham, R.	10,250	6 p.m., ? 30th ,,	110	93
,, ,, H.B.	10,250	7 a.m., 31st ,,	123	83
,, Carupano, B.	11,594	6 a.m., 2nd Sept.	171	68
,, Varinas, B.	12,138	6 a.m., 2nd ,,	172	71
,, ,, R.	12,138	6 p.m., 2nd ,,	184	66
,, S. Christobal, B.	12,228	3 p.m., 2nd ,,	181	68
,, ,, R.	12,228	6 p.m., 2nd ,,	184	66
,, Panama, B.	12,818	3 p.m., ? 2nd ,,	182	70
,, Medellin, B.	12,553	3 p.m., 2nd ,,	181	69
,, Guayaquil, B.	13,116	3 p.m., ? 1st ,,	158	83
,, *C. Southard-Hurlburt*, 17° N. 125° W., R.	15,936	6 p.m., 3rd ,,	211	76
,, *Superb*, 16° S. 148° 45′ W., R.	17,745	6 p.m., 4th ,,	237	75
,, ,, 13° 17′ S. 148° 46′ W., B.	17,711	6 a.m., 5th ,,	249	71
,, *Jennie Walker*, 8° 20′ N. 155° 28′ W., B.	17,987	5 p.m., 4th ,,	236	76
,, Fanning Island, B.	18,278	4 p.m., ? 4th ,,	236	77

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* The local time of first appearance has been assumed to be 6 a.m., where the hour was not recorded.

† This value is probably erroneous. The haze, which seems to have been only slight on the 27th, would be due to previous eruptions. The figures thus marked, and those in brackets in the next column, are not included in the subsequent calculations.

——	Distance from Krakatoa, in English Miles.	Local time of their appearance.	Interval to nearest Hour.	Rate per hour to nearest Mile.
Krakatoa to Maalaaea, R...	17,976	5 a.m., 5th Sept.	249	72
,, Honolulu, B.R.	18,094	5.30 p.m., 5th ,,	261	69
,, *Papa*, 10° N. 161° 21′ W., H. ..	18,380	Noon, 4th ,,	232	79
,, ,, 8° N. 161° W., B.	18,369	6 a.m., 5th ,,	250	73
,, Strong Island, B.	20,818	6 a.m., 7th ,, (E. time.)	276	75
,, Iloilo, B.	23,275	6 a.m., 9th ,,	327	71
,, Colombo, B.	26,713*	4 p.m., 9th ,,	340	79
,, *Glengoil*, 900 English miles E. of Galle, B.	25,947*	6 a.m., ? 9th ,,	329	79
,, *Scotia*, 12° N. 51° E., B.	28,297*	6 a.m., 9th ,,	332	85
,, *Carola*, 11°·25 N. 19°·9 W., B. ..	33,082*	5 p.m., 14th ,,	467	71
,, *Queen of Cambria*, 14° N. 26° 42′ W., H.	33,297*	2 p.m., ? 13th ,,	441	75
,, *Queen of Cambria*, 14° 36′ N. 27° 2′ W., B.	33,275*	6 p.m., 14th ,,	469	71
,, Barbadoes, B.	35,588*	3 p.m., 15th ,,	492	72
,, *Superb*, 12° 12′ N. 146° 7′ W., B. ..	41,695*	6 a.m., 17th ,,	536	78
,, Colombo, B.	51,446†	5 p.m., 22nd ,,	653	79
,, Duem, B.	53,495†	6 a.m., 24th ,,	693	77
,, *Olbers*, 9° S. 35° W., B.	58,730†	6 p.m., 28th ,,	805	73

* Distance from Krakatoa, plus the circumference of the globe at the latitude of the station.

† ,, ,, ,, twice the ,, ,, ,, ,, ,, ,, ,,

Subsidiary Measurements taken from Intervening Localities.

B. C. = Blue sun in first-named and Coppery sun in last-named locality.

——	Approximate Meridional Distance between the stations in English Miles.	Interval to nearest Hour.	Rate per hour to nearest Mile.
Maranham to Fanning Island, B.	7,954	113	70
Panama to *Zealandia*, about 160° W. 5° N., B.	5,496	68	81
Carupano to *Papa*—161° 21′ W., B. ..	6,677	79	85
Papa to Strong Island, B.	2,464	45	55
Fanning Island to Strong Island, B.H. ..	2,624	36	73
Honolulu to *Belfast*—16° 56′ N. 87° 17′ E., B.	7,516	76	99
Jennie Walker to *Belfast*, B...	7,889	103	77
Corona to Fanning Island, B.C.	9,560	113	85
,, Guayaquil, B.C.	4,076	35	116
,, ,, R.C.	4,076	49	83
Seychelles to *Corona*, B.H.	5,282	79	67
Queen of Cambria to *Superb*, B.H... ..	8,032	102	79
10° 4′ N. 26° 30′ W. to 10° 30′ N. 122° E. (Iloilo), B.	14,408	182	79
Queen of Cambria, 9° S. 28° W., to *Queen of Cambria*, 15° N. 26° 42′ W., H.	24,271	288	84
Guayaquil to *Papa*, 161° 21′ W., H. ..	5,602	78	72
Corona to *Papa*, 1° 20′ S. 20° W., 10° 19′ N. 161° 21′ W., H.	9,655	110	88
10° 40′ N. 26° 30′ W. to Panama, B. ..	3,610	37	98
Corona to Panama, B.	4,032	59	68
Seychelles to Carupano, B.	8,149	128	64
,, Maranham, B... ..	6,870	80	86

——	Approximate Meridional Distance between the Stations in English Miles.	Interval to nearest Hour.	Rate per hour to nearest Mile.
Ardgowan to Seychelles, R.	2,033	26	78
St. Helena to 16° 5′ S. 148° 45′ W., R. ..	9,518	144	66
10° N. 26° W. to 17° N. 125° W., R. ..	6,665	103	65
Carupano to Maalaaea, R.	6,200	77	81
,, Honolulu, R.	6,302	91	70
Seychelles to Maranham, R.	6,870	79	87
Corona to Fanning Island, R.	9,560	129	74
British Envoy to *C. Southard-Hurlburt*, R. .	6,251	90	70
Earnock, 11° N. 25° 30′ W. to Trinidad, 11° N. 61° 30′ W., R.	2,444	40	61
Rodriguez, 19° 50′ S. 62° 30′ E., to St. Helena, 16° S. 6° W., R.	4,476	63	71
Maranham, 44° W. 2° 30′ S., to *Jennie Walker*, 8° 20′ N. 155° 28′ W., R.	7,686	126	61
C. Southard-Hurlburt to Maalaaea, R. ..	2,033	38	54
Seychelles to Carupano, R.	8,149	140	58

From these tables we find that the speed of westward progression of the blue sun phenomena, shown by taking an average of the rates in the above list, was 70·4 miles an hour for the first circuit of the earth, 76·4 for the second circuit, and 76·3 for the first half of the third circuit, taking Krakatoa as the starting point for each distance; and by taking the intervals of time between intermediate points in the first circuit, 80·1. Seven of the best* data in the first circuit give a rate of 76·3 miles an hour from Krakatoa to the various localities.

The speed of progression of the haze in the sky was† 70 miles an hour for the first circuit, 77·2 for the second, and 76 between points in the first circuit. Taking two of the best observations—one in 26° 30′ W., and the other in 161° W. (the *Papa*)—the rate between these points appears to have been 80·3 miles an hour, which is probably near the true maximum speed.

The speed of progression of the red fore-glows and after-glows in the first circuit was 76; or, excluding Natal, as affected by previous eruptions, 74·8. The mean of eight of the best observations‡ gives 72·2 miles an hour, from Krakatoa to the various localities. For intermediate points the speed was 72 miles an hour by the mean of twelve observations.

The first observation of a blue or rayless sun west of Africa was at Maranham, giving a rate of 83 miles; the first observation of a peculiar hazy or leaden sky was that of a German ship, in 10° N., 26° W., giving a rate of 83·7 miles; and the first unmistakeable appearance of the red glow was at St. Helena, giving a rate of 80 miles an hour. These figures nearly agree with the rate (83 miles) given

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* Viz.: *Corona*, Varinas, Guayaquil, *Superb*, Fanning Island, *Papa*, Honolulu.

† Excluding the observations on the 27th as probably due to previous eruptions.

‡ Viz.: Mauritius, St. Helena, *Corona*, *Olbers*, *British Envoy*, Varinas, *Superb*, Maalaaea.

by the first blue sun observation at Guayaquil, taking Krakatoa as the starting point. The highest calculated rates are obviously the nearest to the true speed, for in many instances the phenomena would not be noted till after the condition had prevailed for some hours; and the atmospheric change producing the red glows would not be noticed during the daylight or night-time. The rate of progression of all three phenomena in a westerly direction may therefore be taken as between 81 and 84 miles an hour at the maximum; but the main body, causing the most conspicuous appearances, travelled at the rate of only about 72 miles an hour in the first circuit, if the date of starting is correct. Possibly the speed of the second circuit was somewhat greater, or the matter becoming added to that which remained in the subjacent upper air from the first passage more speedily produced noticeable glow effects. Moreover, observers may have been more ready to note at once unusual appearances. The calculated speed is more reduced in the first than in the second and third circuits by assuming the eruption to have occurred on the 26th, if the phenomena were really due to the eruption of the 27th; so that it is probable that the most conspicuous blue sun phenomena at great distances from Krakatoa were produced by the explosions which occurred early on August 27th, and in that case the propagation must have been considerably more rapid than that shown by the list. For instance, the rate to Panama would be 79 miles an hour instead of 70, supposing the great eruption at 10 a.m. to have been the cause of the blue sun.

Places near the same latitude as Krakatoa and near the Equator were earliest affected by haze and solar obscuration. The difference between the rates resulting from different places of observation would possibly be accounted for by the clouds of matter from the several explosions between 2 p.m. on August 26th and 10 a.m. on August 27th not consisting of a continuous mass but of streams of unequal density and at different altitudes. As the eruptions succeeded each other in a large number of explosions, the intensity of which varied, the height attained by the ejecta would not be the same throughout. The slight haze seen at Seychelles, Rodriguez, Ceylon, and Labuan on August 27th, can hardly be ascribed to the explosions of that day, but were more probably due to the eruptions of the night of August 25th–26th, or of the 26th, or even of the previous week.

A very heavy outburst must have occurred about 11.25 a.m. on August 26th, as the barometer rose and fell about $\frac{3}{10}$ths of an inch on board the *Lennox Castle* in 91° E. (see Section II., p. 269); and the eruption sounds heard at Ceylon at 7 a.m., which must have originated at about 5 a.m. on the 26th, showed that early on this day the volcano was already violently active.

The influence of an incorrect date at the starting-point is so much reduced in the second and third circuits that the rates given by these are probably near the true speed. We have thus for the blue sun, second circuit, 76·4 miles, first half of third circuit, 76·3 miles. These rates thus agreeing with the 76·3 miles obtained from the intervals between Krakatoa and points in the first circuit, where some of the best observations were made.

For the sky haze, we get 77·2 miles an hour for the second circuit, compared with 76 for intermediate points in the first circuit.

For the red glows there is no definite second or third circuit, but the mean of six of the best pairs of observations* at intermediate points in the first circuit gives 71 miles an hour.

From these figures we may infer with some force that the eruption which caused most of the blue suns, lofty haze, and red glows at distances beyond two or three thousand miles from Krakatoa on the given dates, occurred not on August 26th but on August 27th, for in that case the calculated speed of the first circuit approximates very closely to that of the second and third circuits and for distances between intermediate points.

But there seems to be little room for doubt that the earliest effects in the Atlantic and Pacific and at Maranham were in part due to the eruption of the 26th. Therefore, it seems undesirable to calculate from all the data on the assumption of the phenomena being due to the great outburst of the morning of the 27th; and the initial date is accordingly taken as 2 p.m. on August 26th, though doubtless the explosions of that afternoon caused only a part of the effects. The speed of the red glows approaches remarkably near to that of the sky-haze, considering that they were mostly seen only north and south of the main stream of hazy matter, that is, where the haze was less dense and probably slightly less lofty. This close approximation to the speed of the main Equator stream from east to west indicates that the red glow when first seen was caused by the spread northwards or southwards of matter detached from the main stream at no great distance; for, a passage through many degrees would have been subject to appreciable retardation of the east to west movement by the slower motion of the earth in higher latitudes. As there is no reason to suppose that the process of precipitation of particles from the main stream abruptly ceased in the Indian Ocean, the sporadic glows seen far north and south of the blue sun area during the first circuit would, in all probability, be largely caused by the descent of the less finely divided matter into upper currents which would rapidly convey it beyond the tropics, and temporarily add to the brilliancy of sunset skies in regions unaffected, till long after, by the cloud of much lighter particles composing the main body of the haze stratum.

F. A. Rollo Russell.

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* Namely: St. Helena to 16° 5′ S. 148° 45′ W.; 10° N. 26° W. to 17° N. 125° W.; *Corona* to Fanning Island, Rodriguez to St. Helena; Trinidad to Honolulu; and *British Envoy* to *C. Southard-Hurlburt*.

PART IV., SECTION IV.

DIURNAL AND SECULAR VARIATION IN THE DURATION AND BRILLIANCY OF THE TWILIGHT GLOWS OF 1883–84, AND THE HEIGHT ABOVE THE EARTH OF THE STRATUM WHICH CAUSED THEM.

By Mr. E. DOUGLAS ARCHIBALD.

The height of the stratum which produced the fore and after-glows in 1883–84 can be approximately determined from the depression of the sun when the ulterior margin of each is at some measured angle above the horizon, or on the horizon, or from the angular elevation of the zones of maximum brilliancy. Since, in most cases, the total duration alone of the phenomenon was recorded, the heights are chiefly determined from horizontal observations.

Before, however, we proceed to exhibit any of the results obtained by this means, we must refer to the fact, noticed by many observers, of a secondary as well as a primary glow; the latter lasting usually from 50 to 60 minutes before or after sunrise or sunset, while the former lasted in most cases about double this time. This circumstance has been thought by some to be a feature peculiar to these sunsets, and not hitherto observable; and the following letter of Prof. N. STORY MASKELYNE, F.R.S., to 'Nature,' January 24th, 1884, certainly seemed at first to countenance this idea :—

> "What is worthy of especial interest is the great difference between the periods of prolongation then and now of the illumination of the western sky, showing that the second after-glow of recent sunsets is a phenomenon distinct from, and additional to, those belonging to normal sunsets.
>
> The following table exhibits the two series of observations made in 1855, 1856, 1857, and in 1883–84 respectively :—

Date.	Sunset at.	First after-glow or cone of pink light.				Second after-glow in 1883-84, which begins as the first after-glow sets.
		Appears as sunset colours are fading.	Brightest at.	Sets.		
				1st series, 1855-56-57.	2nd series, 1883-84.	
	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.
November 11, 1856	4 13 }	4 50	4 57	5 10		
" 12, "	4 14 }					
" 23, 1855	..	..	..	4 55		
December 7, "	3 50	..	..	4 20		
" 8, "	..	..	..	4 20		
" 10, "	..	..	..	4 20		
" 11, 1883	..	..	..	..	about 4 45	5 45
" 14, "	..	..	..	..	..	5 45
" 15, 1856	..	4 15	4 21	4 35		
" 18, "	..	..	4 20	4 30		
" 19, "	3 50	..	..	4 30		
" 24, 1883	3 53	..	..	..	about 5 0	5 45
January 11, 1884	4 13	..	..	..	" 5 0	5 40
" 12, "	..	..	..	..	" 5 0	5 55
" 15, 1857	..	..	..	4 55		
" 16, "	..	4 50	..	5 0		
" 19, "	..	..	5 10	5 18		
" 26, "	..	..	5 20	5 25		
February 8, "	5 0	..	..	..		

The colours associated with the actual sunset are quite in accord in both.

The first after-glow, or pink cone or dome of light appearing after the sunset colours have nearly faded, is also similar in both series; but its time of setting has been apparently somewhat prolonged in the recent observations.

It is the 1883–84 series alone, however, that shows the *second* after-glow; and the duration of this strange phenomenon, which I have the advantage of observing over a wide bird's-eye view in North Wiltshire, has extended on evenings when it could be well observed to about one hour after the first after-glow had disappeared below the horizon. The exact moment of this disappearance has been more difficult to determine than in the earlier observations where darkness followed; as recently the heavens and the earth have been re-illuminated just as the natural night would have begun.

N. STORY MASKELYNE.

Salthrop, *January 13th.*"

When we go further back, however, we find records of certain epochs of sunset glows not only equal in duration to those under discussion, but closely resembling them in many other details.

Thus, in the 'Bibliothèque Universelle' (Nouvelle Série, XXIII., 1839, p. 382, MM. Necker and De La Rive), a table is given showing the time at which the glow disappeared on the high mountains of the Alps. This varied generally from 12 to 45 minutes after sunset; but from October 16th to 21st, 1837, it was 1 hour 28 minutes, and in June, 1834, a little over an hour. A detailed description of the phenomena, as seen near Geneva, says :—"In the period from June to September the glow leaves the east quarter 42¾ minutes after sunset, and from September to December 30 minutes after sunset. From October to February the time after sunset at which the red glow appears in the west averages 35 minutes. It disappears at 59 minutes after sunset."

The maximum duration of 96 minutes in 1837 is as long as the average of the secondary glows of the present series, and if 59 minutes is to be considered a primary glow, it is just about the same as that of the primaries of 1883–84.

Similar prolonged twilights and glows are recorded as occurring in 1831 in different parts of Western Europe and America. Thus :—

"On the 24th, 25th, and 26th of September [1831], from Madrid to Odessa, twilight was prolonged up to 8 p.m., or nearly two hours."*

Again, in 1846 extraordinary after-glows are recorded as occurring in Switzerland from the middle of April to the end of May.

The durations of four were :—

90	minutes on	May 21st.
80	,,	May 23rd.
85	,,	May 28th.
45	,,	May 31st.

The first three here evidently correspond to the secondary, the last being probably a primary glow.

Again, in the 'Comptes Rendus' (vol. xlviii., 1859, p. 109), in a description of certain crepuscular effects witnessed off the coast of Africa in a voyage from France to Rio de Janeiro in July, 1858, the following passage occurs, in which a secondary glow is referred to :—

"Soon after sunset a redness appeared in the east; 11 minutes after, a redness in the west, above a white sheen. The red band sets when the sun is 11° 42′ below the horizon. Then a second '*arc rose*' appears in the east when the first is setting, and passes to the west without appearing at the zenith, and sets when the sun is 18° 18′ below the horizon. Sunrise phenomena were corresponding, but the secondary '*arc rose*' occurred when the sun was 17° 22′ below the horizon, and the primary when the sun was 10° 50′ below the horizon."

Another description of similar phenomena, seen about the same period off the east coast of South America by BURKHART-JEZLER, is to be found in 'Poggendorff's Annalen' (No. 145, 1872). The following is a summary of what has a bearing on the present series :—

"On the east coast of South America, in January, 1856, and in 1857 and 1858, a wonderful *arrebol*, as it is there called, or twilight-glow, was observed. The place

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* Kaemtz's 'Meteorology,' Walker's translation, p. 411.

of observation was lat. 26° 18′ S., long. 30° 50′ W. ; and the phenomena were seen also in 1857 and 1858 in Desterro, lat. 28° S. The *arrebol* occurred only when the air was quite transparent, as after dew or rain. In June, 1858, it appeared after a long absence. It began 14 or 15 minutes after sunset, and ceased 55 minutes after sunset. Then a second glow appeared, sea-green and golden, which lasted 1 hr. 30 mins. after sunset. The glow exhibited a splendid violet near the zenith. At about 22 minutes after sunset the order of the colours from the zenith was as follows : violet, blue (light), green, yellow, orange. At the same time a mixture of white, green, yellow, and red, rose to 40° or 55° in the east. There were fine feathery clouds in the sky. Shadows cast by the *arrebol* lasted 40 minutes. At Bahia, there was no *arrebol* for three years from 1858 ; but they have there a constant thin transparent haze, not blurring the outlines of very distant objects. When seen, the margin of the *arrebol* passed the zenith at 28 to 30 minutes after sunset. Maximum light in the west, 43 to 45 minutes ; yellowish glow, 1 hr. 30 mins. ; white do., 2 hours after sunset."

The above description of the *arrebols* of South America is remarkably similar in many points to that of the glows of 1883–84, especially as regards the durations of the primary and secondary glows, and the zenithal passage of the ulterior margin of the former. They appear to have differed, however, in one essential feature, viz., the order in which the colours were arranged from the zenith downwards, the red or purple being uppermost during the first part of the present series, and sinking towards the horizon only at the close of the phenomenon ; while, in the *arrebols*, there seems to have been no inversion, but only an intensification of the tints which characterise an ordinary twilight glow.

Another peculiarity characterising the present series was the difference in definition between the primary and the secondary.

The Rev. S. E. Bishop, writing to 'Nature,' April 10th, 1884,[*] says :—

> "I beg special attention to my former remark of the 'earth-shadow sharply cutting off' the upper rim of the first glow. This was very manifest in the strong heavy glows of September, showing clearly that the first glow directly reflected the sun's rays, while in the after-glow, which had no defined upper rim, but continued much longer, the haze reflects only the light of the first glow. This bears on estimates of the height of the haze."

And in a later letter to the same journal, dated June 26th,[†] he writes as follows :—

> "In your issue of April 10th (p. 549) is the statement by an observer in Australia that the 'red glow was margined by an immense black bow stretching across from north-west to south-east.'
>
> "I wish to say that the above language almost exactly describes the appearance to which I alluded on the same page as 'the earth-shadow cutting off the upper rim of the first glow.' The 'black bow' of the Australian was evidently the shadow of the horizon projected on the haze stratum. In both the

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[*] 'Nature,' vol. xxix., p. 549.

[†] 'Nature,' vol. xxx., p. 194.

above cases the lower surface of the haze was evidently well defined, so that, as the horizon intercepted the direct rays of the sun, a well-marked shadow moved westward and downward. Above this black rim or bow appeared the secondary glow, produced by the reflection of the sun's rays from that portion of the haze surface which was directly illuminated. Very often the second glow was more conspicuous and impressive than the first, because it shone against the dark sky of night.

"In the 'Proceedings' of some association I have just read an astonishing estimate of the height of the haze as 141 miles, based on the fact that it received the sun's rays one hour after sunset, the fact being strangely overlooked that the late reflection was a secondary one."

Another observer, the Hon. F. A. Rollo Russell, has noticed the same difference in the definition of the edge of the two glows, and this observation has been more recently confirmed by Professor Riccò, of Palermo,* who, in his summary of the optical effects, says: "The contour of the second glow was not definite like that of the first."

The following is a list of those who have observed two distinct glows :—

List of Observers of two Glows at Sunrise or Sunset.

Name.	Locality.
(1) Charles Todd	Adelaide.
(2) Miss Annie Ley	Ashby Parva, Lutterworth.
(3) E. Divers	Tokio, Japan.
(4) Dr. C. Meldrum	Mauritius.
(5) S. E. Bishop	Honolulu.
(6) Prof. O. N. Stoddard	Ohio.
(7) L. Hargrave	Sydney.
(8) F. A. Rollo Russell	Richmond, Surrey.
(9) H. Janesch	Laibach.
(10) B. J. Hopkins	Dalston.
(11) Herr Metzger	Flensburg.
(12) Prof. W. Köppen	Hamburg.
(13) Bucchich	Lesina.
(14) Arcimis	Madrid.
(15) F. Gillman	Madrid.
(16) Prof. von Bezold	Munich.
(17) F. Terby	Louvain.
(18) Laugier	Rambouillet.
(19) O. Jesse	Berlin.
(20) W. G. Brown	Massachusetts.
(21) Prof. N. Story Maskelyne..	Salthrop, Wiltshire.
(22) J. Aitken	Edinburgh.
(22a) M. L. Cruls..	Rio de Janeiro.

Of these, Messrs. Divers, Bishop, Stoddard, Jesse, Laugier, and Aitken, express themselves strongly in favour of the notion that the primary glow is produced by the direct rays of the sun, illuminating the particles of matter suspended in the atmosphere; and that the secondary glow is the reflection, by the same stratum, of a primary glow which is below the western horizon.

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* 'Reale Accademia dei Lincei,' series 4a, vol. ii., January 3, 1886.

Amongst other reasons for this opinion we note the following :—

1. The respective durations of the two glows; the first averaging 54 minutes, and the second 96 minutes from sunset until their disappearance on the horizon, or from their appearance on the horizon until sunrise.

The observations from which these preliminary averages are taken are given below.

Observer.	Locality.	Duration in Minutes.		Date.
		Primary.	Secondary.	
(23) Jesse	Berlin	50	120	Jan. and Feb., 1884.
(24) Russell	Richmond, Surrey ..	56 (Mean of 17 observations, Nov. 9 to Dec. 23.)	94 (Mean of 15 observations.)	
(25) Rebeur-Paschwitz .	Berlin	64	101	Dec. 18, 1883.
(26) Bucchich	Lesina	56	100	Jan. 4, 1884.
(27) Hargrave	Sydney	48	98	Dec. 25, 1883.
(28) Terby	Louvain	51	120	Nov. 27, 1883.
(29) Meldrum	Mauritius	40	76	(Nov.), 1883.
(30) Divers	Tokio..	50	90	(Nov. and Dec.) 1883.
(31) Thollon	Nice	55	90	Dec. 1, 1883.
(32) Meldrum	Mauritius	38	77	Dec., 1883.
(33) Gillman	Madrid	51	101	Dec. 4, 1883.
(34) Maskelyne.. ..	Salthrop, Wiltshire..	55	105	Dec. 11–14, 1883.
		67	107	Dec. 24, 1883.
		47	102	Jan. 11, 1884.
General means	.. ..	54	96	

The durations alone, while they are sufficiently proportionate to the solar depression to serve to illustrate the wide distinction between the two glows, cannot be taken to show the exact relation between them. For this purpose we must use the corresponding angles of solar depression.

Excluding Mr. Russell's series and Mr. Maskelyne's, the remaining ten give for the ratio of the values of the solar depression at the close of the two phenomena the following value :—1·8 : 1.

Dr. Hellmann, in his article on the duration of twilight ('Meteor. Zeits.,' January, 1884), quotes Dr. von Bezold's article ('Pogg. Ann.,' c. xxiii., 1864), in which he says :—The ratio of the solar depression, at the time of greatest intensity of both purple lights of the ordinary twilight glow, is 2·2 : 1. He himself found, for Spain, a mean ratio of 2·4 : 1, single values varying from 3·4 to 1·8, owing to the difficulty of determining the end of the second glow. For the present series of unusual glows, Dr. Hellmann found from three good observations, on November

29th, December 31st, 1883, and January 1st, 1884, a mean ratio of 2·5 : 1; and from Mr. RUSSELL's observations, a ratio of 2·4 : 1. Professor RICCÒ in his paper (frequently quoted from, elsewhere) simply says that the depression of the sun at the end of the secondary glow was approximately double that at the end of the primary; from which, amongst other reasons, he concludes the latter to be a reflection of the former.

2. The fact that in the extra-tropics the primary was seen to rise in the east, pass overhead about 33 minutes, and set in the west about 54 minutes, after sunset; and that soon after the setting of the primary glow, the secondary, in like manner, rose in the east, passed overhead, and sank similarly in the west, about 96 minutes after sunset.

3. That, in cases where cirrus-cloud was present, the glow-stratum was noticed to begin to shine between only 20 and 29 minutes later than the cirrus above which it floated.*

4. The re-illumination of the lower clouds, evidently by reflection, when the primary glow approached the horizon, and the apparent increase of light (very often referred to) when the secondary glow reached its maximum some little time after this.

5. The fact acutely set forth by AITKEN,† that the second glow is not visible until the sun's rays have passed out of that part of the air in which the particles are small enough to reflect chiefly blue light.

6. The fact that, even in ordinary circumstances, a second "crepuscular" glow has been noticed, which has been unhesitatingly attributed to reflection from the primary.

We quote the following from 'Kaemtz Meteorology,' Walker's translation, p. 409:—

> "When the crepuscular curve, formed by the shadow of the earth, projected on the high regions of the atmosphere, sets in the evening on the western horizon, we may still, in very favourable circumstances, perceive a feeble and whitish light illuminating the sky towards the north-west and which sometimes rises to a considerable angular height. This light is incontestably due to secondary illumination thrown on the higher points of the atmosphere, by strata of air situated, at that time, below the horizon, and directly illuminated by the sun; the light of this atmospheric space is due to rays that have already undergone a first reflection, which M. BIOT names 'the second crepuscular space.'
>
> "It does not appear that this second twilight can be observed from our valleys; but on high mountains it is very frequently visible. DE SAUSSURE observed it when on the Col du Géant; the light attained to as much as 30° above the horizon; the depression of the sun below the horizon was at the time 22°. M. BRAVAIS observed it on the summit of the Faulhorn, 2683 metres (8803 feet) above the level of the sea, several times during the years 1841 and 1842."

Then follows a table of M. BRAVAIS's observations, six of which give a mean

---

* Showing that it was at no very great elevation in the extra-tropics.

† Second note on the Remarkable Sunsets, by Mr. JOHN AITKEN. 'Proc. Royal Society,' Edinburgh, vol. xii., p. 647.

depression for the sun = 18°·5; which is about the average depression for the limit of twilight. He then goes on to say :—

> "If it is true that the ordinary crepuscular curve exactly coincided with the curve of the passage of the earth's shadow out of our atmosphere, this second crepuscular curve ought itself to be interpreted in an analogous manner; and we might use it with advantage to determine the height of our atmosphere."*

It is evident from this that if the upper regions of the atmosphere were more than ordinarily full of dust, or other reflecting matter, this second crepuscular space might be rendered more generally conspicuous and coloured than in the cases mentioned above.

There are, besides, many other points noticed by different observers which confirm the same view; amongst others, one by AITKEN in the paper referred to above, where he distinctly says that the secondary glow was observed to proceed from the same filmy clouds which produced the primary glow; and, further, that "it was always possible to tell whether the second glow would be brilliant or not before it made its appearance. If the horizon colours were high up and brilliant then there always followed a brilliant second glow, but if they were low and dark no second glow followed. There was thus a direct relation between the brilliancy of the sunset colour and the second glow."

Regarding the re-illumination of the lower clouds by reflection when the primary glow was near the horizon, AITKEN says: "As far as I have been able to judge, the second glow which illuminated the whole heavens was produced in exactly the same way as the second illumination of the clouds." And in connection with this view the following letter is important, as it was written before the observer had noticed the real existence of a secondary glow.

The author of this paper, writing to 'Nature' on December 20th, 1883, said :—

> "On Thursday, December 6th, I witnessed one of these gorgeous sunsets in company with a friend, from the top of Rusthall Common, near Tunbridge Wells. Like Mr. ROLLO RUSSELL, I noticed that the peculiar lasting glow came from a lofty stratum of pale, fibrous, nearly transparent, cirriform haze which was almost invisible as the sun set, but afterwards came gradually into view, at first white in colour, and then gradually changing to orange, pink, and finally red, the change to pink occurring at 4.25 and to red at 4.45.
>
> "We observed also a strange reactionary effect produced by this glow, viz., that long after the red tints had faded from the ordinary cirrus in the western sky and from some snow-shower cumuli in the east, they were both re-lighted by the glow which had meanwhile increased in the west.
>
> "On Friday this reflection on to low clouds all over the sky from the undoubtedly lofty stratum in the west was more noticeable, and it at once struck me that persons who had not observed the entire process of the extinction of the real reflection of the sun by these clouds, and their subsequent re-illumination by reflection from the upper glow (as Miss LEY terms it), might erroneously be led to attribute this secondary illumination to their reflection of direct sunlight. On this ground alone I

---

* The whole of this passage seems to have dropped into oblivion.

should be rather inclined to accept with a little hesitation the observation on which Professor VON HELMHOLTZ bases his calculation, viz., that the clouds which were illuminated directly by the sun were 45° above the horizon one hour after sunset."

The alternative hypothesis which has been suggested, of two distinct strata, one of which is about double the height of the other, does not seem to have a particle of corroborative evidence in its favour, and is, moreover, *à priori*, improbable, as there seems to be no reason why the reflecting stratum, whether derived from cosmical or from terrestrial sources, should occur in two definite layers.

The failure on the part of many observers to entertain the possibility of a reflected primary sunset has led to some very widely and often absurdly divergent estimates being made of the height of the reflecting stratum, and it is evident that persons who simply noted the duration of the entire phenomenon, without paying attention to its minor details, would miss all those phasal changes which, to careful observers like MELDRUM, BISHOP, RUSSELL, and others, afforded clear evidence of a difference in the source of the light as the phenomenon progressed.

A glance at the following table, which represents the principal items we have been able to collect on this point, will show the main reason for their apparent discrepancy :—

The Height of the Stratum which Produced the Glow Effects, Estimated by Different Observers.

Observer.	Locality.	Height in Feet above Sea Level.	
(2) Miss Annie Ley	Lutterworth	68,640	Group I.
(35) N. S. Shaler	America	50,000	
(10) O. Jesse	Berlin	55,772	
(36) Dr. Galle	Leipsic	52,800	
(38) P. Estrelle	Portugal	65,618	
(39) J. Aitken	Edinburgh	about 71,280	
(40) Meidinger	..	about 36,450	
(41) G. A. Hirn (from noticing glow continue two hours after sunset, and assuming it to be the effect of direct sunlight).	France	1,640,450 (!)	
(37) von Helmholtz *	Berlin	40 miles or 211,200	Group II.
(42) Ch. Dufour	Morges	229,663	
(43) Herr F. Pockels (from an observation lasting 90 minutes).	Brunswick	147,640	
(44) Perrotin and Thollon (from mean of December observations).	Nice	164,045	
(45) Dinklage (mean of two observations on December 31).	Hamburg	218,179	
(46) B. Brauner (November and December)	Prague	264,000	
(47) Professor Ragona	Modena	193,248	

* He evidently deduced this height on the supposition that the sun is shining directly on the stratum at 45°, one hour after sunset, as may be seen from his description of the phenomenon in which darkness supervenes on the first glow, and "sky was again coloured by a pink or crimson glow."

Now, it will be noticed that the heights in the preceding list, with the exception of the abnormal value assigned by M. HIRN, range between two very different groups of values—one averaging 57,222 feet, and the other 203,996. It is not possible to find out in every case the precise method of calculation employed by the observer, but in several, where the duration of glow or the solar depression is given, it is easy to see whether the secondary glow was taken to be direct sunlight or not.

In the first group—

Miss ANNIE LEY calculates from primary glow.
N. S. SHALER, uncertain.
O. JESSE, from primary at different angles.
Dr. GALLE, uncertain.
P. ESTRELLE ,,
J. AITKEN, assumes secondary to be reflection of primary.
MEIDINGER, uncertain.

In the second group—

VON HELMHOLTZ assumes direct sunlight all through.
CH. DUFOUR ,, ,, ,,
Herr F. POCKELS ,, ,, ,,
PERROTIN and THOLLON, uncertain.
DINKLAGE, uncertain.
BRAUNER, direct sunlight all through.

Now, though about some of these there is a little uncertainty as to what exact hypothesis was adopted, there is a very strong probability that those in the first group were calculated either from the primary alone or from the primary on the hypothesis of direct sunlight, and the secondary as a reflection from it; and the second group from the secondary alone (*i.e.*, from the total duration of the phenomenon) on the hypothesis that it was entirely due to direct sunlight. The uniformity of the figures in the two groups favours this conclusion, and also the fact that the figures in the second group, if converted into solar depression, and treated by the formula on the hypothesis of two reflections used hereafter, would approach remarkably close to the average of the first group.

A result given by the Rev. S. HAUGHTON, M.D., F.R.S., in a paper read before the Royal Society of Dublin, January 21st, 1884, shows a similar ratio between the heights of the ordinary twilight-producing stratum on the two hypotheses.

Thus, for a solar depression = 18°, the height of the twilight-producing stratum is—

40 miles, or 211,200 feet, on the hypothesis of one reflection from direct sunlight, and
12 miles, or 63,360 feet, on the hypothesis of two reflections,

figures which correspond remarkably closely with the 203,996 feet and 57,222 feet given above.

More recently Professor Riccò, from twenty observations taken between December 3rd, 1883, and April 30th, 1884, has deduced the following values for the height on the provisional hypothesis of direct sunlight all through :—

	Number of Observations.	Height of Stratum, in Feet.
Primary	14	57,414
Secondary	6	279,470

Figures which are somewhat similar to those quoted above ; but he adds :—" Since the depression of the sun, in the case of the secondary glow, was approximately double that in the primary, it seems probable that the secondary was the reflection of the primary by the atmosphere." He notices also the absence in the secondary glow of the diverging crepuscular beams which were often conspicuous in the primary, and which he attributes to the obstruction of the sun's tangential rays by mountains or clouds on the horizon—a proof that the latter was due to direct, and the former to reflected, sunlight.

Therefore, in the subsequent discussion of the reports of the durations of the glows which have been gathered by the Committee from the sources at their disposal, we have decided to accept the hypothesis of the primary glow being a first reflection, and the secondary glow a second reflection of the solar rays.

It has not always been easy to determine whether the duration, in every case, included the secondary as well as the primary glow, as such duration, *ceteris paribus*, is a function of the latitude and season ; but by comparison of the ratios of the duration of the two phenomena when observed together, it has been possible in most cases to determine fairly accurately whether the duration given was that of the primary or of primary and secondary together.

In some cases there seems to be reason to suppose that there may have been even a tertiary glow* arising from a third reflection, as where the total duration was two hours near the equator, or over two hours near the poles ; but there seems little positive evidence of this ; and as the chances are about equal that in some cases the duration of the entire phenomenon was given too short, while in others it was made to cover not merely the glow itself, but the ordinary twilight which was observed to be slightly prolonged during their maximum brilliance, the averages should thus give fairly correct results.

The methods by which the heights were calculated in special cases are as follows :—

---

* Professor Riccò, in his summary already referred to, notices this point as follows :—" Somewhat rarely, after the secondary, a tertiary very weak reddish light remained, but this was not observed so closely as to exclude the probability of its being due to zodiacal light."

The angle of the sun's depression below the horizon at the time of the observation is calculated by the ordinary formula for its zenith distance; where

$$\cos z = \sin \delta \sin \phi + \cos \delta \cos \phi \cos h\,;$$

$z =$ the sun's zenith distance;
$\delta =$ the declination of the sun;
$\phi =$ the latitude of the place;
$h =$ the hour angle from true noon.

If α denote the angular depression of the sun below the horizon,

$$\alpha = z - 90^\circ.$$

Taking first the case of the primary glow, or *one* reflection of the direct solar rays, we have, in Fig. 1, Plate XXXVIII., a portion of the stratum observed at a point P on the earth's surface to be illuminated from the horizon H up to the edge represented in section by the point Q, where it is supposed to catch the last solar ray S R Q tangent to the earth at R. Taking Q P H $= \theta$ and O to represent the centre of the earth, and taking Q O R $= \beta$, we can derive the formula for the general case, in which the edge of the glow is observed to be at an angle θ above the horizon, and afterwards by giving θ suitable values, deduce the values for the height of the stratum Q A $= x$ (say) above the earth's surface, (1) when the edge of the glow is crossing the observer's zenith, and (2) when it is just disappearing on the horizon. Taking R to represent the earth's radius, we have at once from the geometry of the figure—

$$\frac{x + \mathrm{R}}{\mathrm{R}} = \sec \beta \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

and

$$\frac{x + \mathrm{R}}{\mathrm{R}} = \frac{\sin (90^\circ + \theta)}{\sin (90^\circ + \theta + \alpha - \beta)} = \frac{\cos \theta}{\cos (\alpha + \theta - \beta)} \quad . \quad . \quad . \quad . \quad (2)$$

from which we readily obtain

$$\tan \beta = \frac{\cos \theta - \cos (\alpha + \theta)}{\sin (\alpha + \theta)},$$

and in a more convenient shape for logarithmic calculation,

$$\tan \beta = \frac{2 \sin\left(\frac{\alpha}{2} + \theta\right) \sin \frac{\alpha}{2}}{\sin (\alpha + \theta)} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

When β is found from this equation x can be found from (1) by putting it into the more convenient form

$$x = \text{R} \tan \beta \tan \frac{\beta}{2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

If we put $\theta = 90°$, from (3) $\tan \beta = \tan \alpha$, and the formula for the case in which the ulterior edge of the glow is at the observer's zenith, is,

$$x = \text{R} \tan \alpha \tan \frac{\alpha}{2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

If we put $\theta = 0$, from (3) $\tan \beta = \tan \frac{\alpha}{2}$, and the formula for the case in which the primary glow is just disappearing on the horizon, is,

$$x = \text{R} \tan \frac{\alpha}{2} \tan \frac{\alpha}{4} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

In Fig. 2, Plate XXXVIII., this case is represented, where S K R H represents the direct solar ray tangential to the earth, and just illuminating the observer's horizon at H. In the same figure, if instead of K R H representing the last direct solar ray tangential to the earth, it represents the first reflection of this last ray, then H P represents the second reflection of the same ray; and the figure will give us a formula for the height of the stratum based on the supposition that the secondary glow when it is just disappearing is a reflection of the primary glow when it is just disappearing on the horizon. A moment's consideration, however, will convince us that such a limiting case can scarcely occur; since, when the primary is just disappearing on the horizon, its illumination would be too feeble to illuminate a portion of sky on the horizon at a distance (calculated from the subsequent average values for the solar depression) of about 622 miles. In fact, instead of supposing the secondary glow to be the reflection of the edge of the primary just as it is disappearing on the horizon, we must suppose it to arise by reflection from the latter while it still covers a fair proportion of the sky. We shall, therefore, assume that the secondary glow is just fading from the observer's horizon, while the primary glow still covers a quarter of the sky above the next succeeding horizon (formed by drawing a tangent to the earth from the point H where the observer's horizon meets the glow stratum).

Fig. 3 represents these conditions, and the geometry of the figure shows us that the angle $\text{H O P} = \frac{2\,\alpha}{7}$, from which we derive the following formula for the height $\text{H A} = x$ of the stratum, viz.:

$$x = \text{R} \tan \frac{2\,\alpha}{7} \tan \frac{\alpha}{7} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

MEASUREMENT OF THE HEIGHT OF SUNGLOW STRATUM.

FIG. 1.

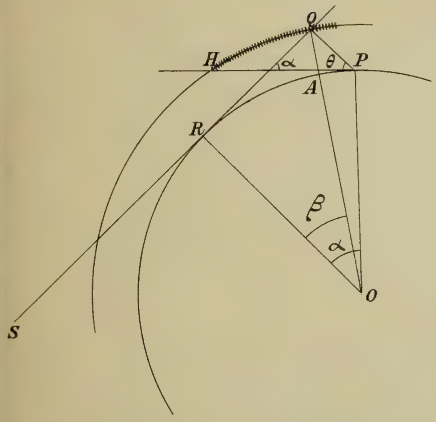


FIG. 2.

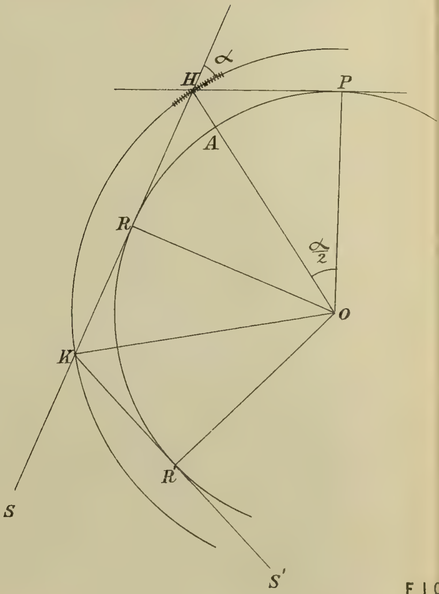


FIG. 3.

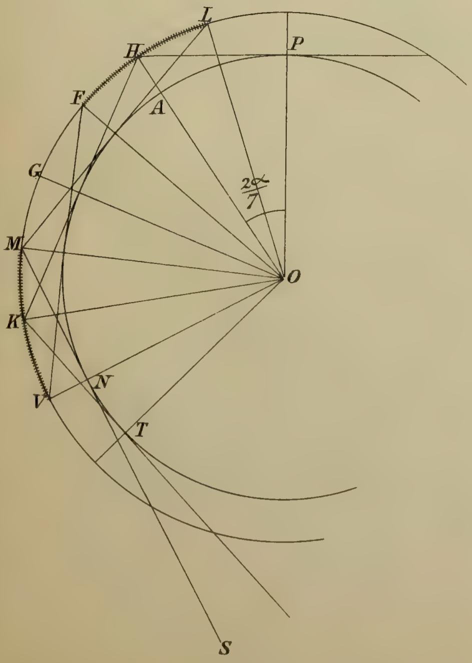
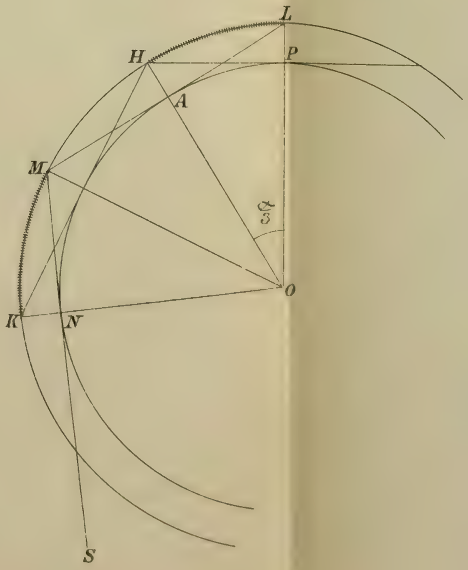


FIG. 4.



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If we adopted the limiting case as in fig. (2) we should have had

$$x = \mathrm{R} \tan \frac{a}{4} \tan \frac{a}{8}$$

which would make x smaller. For the primary, the limiting case represented by equation (6) may be more safely adopted. We have, therefore, decided to adopt equation (6) for the disappearing primary, and equation (7) for the disappearing secondary.

Fig. 4, Plate XXXVIII., represents half the observer's sky illuminated by reflection from a primary glow. This should represent the condition of things at the time when the glow is at its maximum; and the geometry of the figure gives at once the formula

$$x = \mathrm{R} \tan \frac{a}{3} \tan \frac{a}{6} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

The general case of the secondary glow in which the altitude of its ulterior margin is observed to be any angle θ has not been investigated, as it leads to a cubic equation which is not generally solvable.

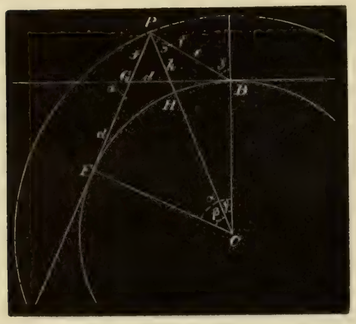
In working out the values, account has to be taken of refraction, and here some difficulty arises as to what ought to be allowed. In the case of the primary glow on the horizon, the last solar ray traverses the entire atmosphere, once to the point where it is a tangent to the earth, thence to the stratum, which would not be so far, and thence to the observer's eye, which would be the same distance as the latter. It would thus have traversed not quite three times the entire atmosphere. For the secondary glow on the horizon this would become not quite five times. Again, we cannot allow even in the primary the entire correction for a purely horizontal ray, since, owing to haze and absorption, the phenomenon could only have received sunlight from, and *à fortiori* been visible at, some little angle above the horizon. In the case of the secondary glow, owing to the relatively weaker light and greater absorption, these considerations would have still more weight. We have, therefore, adopted—as a probable value for the correction to be subtracted from a in the case of the primary—1° 10′, which is a little less than three times the mean refraction at 1° alt. (24′ 49″), and a little more than twice the mean horizontal refraction (33′). For the secondary glow on the horizon, the correction is taken to be 1° 45′, or rather less than five times the refraction at 1° alt. The correction (16′), for the sun's semi-diameter, has not been applied, since most of the observations give the duration from *apparent* sunrise or sunset. With these corrections, and by means of the preceding formulæ, the values given in Table I., p. 357, have been worked out. They comprise most of the observations collected by the Committee before the report was commenced; some having since been taken or discovered which could not well be included after the means from those at first available had been calculated.

Before inserting the values which, by means of the formulæ given above, we have obtained for the height of the glow stratum during the first few months of its most brilliant appearance, allusion must be made to a somewhat similar set of formulæ for a primary glow given by Herr Otto JESSE, in a recent article in the 'Meteor. Zeits.,' vol. iii. (1886), pp. 8 and 64,[*] when dealing with some specially brilliant appearances (perhaps reappearances) of the glows which occurred in June and July, 1885, in different parts of Germany.

In the following figure the meanings of the letters and lines are mostly evident, $G\,B = d = G\,F$ and $P\,G = f$. Instead of $\theta =$ altitude, Herr JESSE employs $\zeta =$ zenith distance of P, the point in the stratum whose illumination is observed from B.

Herr JESSE deduces the following formulæ :—

FIG. 15.



1. $f = \dfrac{d \cos \zeta}{\cos (\zeta - \alpha)}$.
2. $f + d = r \tan \beta$.
3. $d = r \tan \frac{1}{2} \alpha$.
4. $f + r \tan \frac{1}{2} \alpha = r \tan \beta$.
5. $f = \dfrac{r \tan \frac{1}{2} \alpha \cos \zeta}{\cos (\zeta - \alpha)}$.
6. $\tan \beta = \tan \frac{1}{2} \alpha \left[1 + \dfrac{\cos \zeta}{\cos (\zeta - \alpha)} \right]$.
7. $\gamma = \alpha - \beta$.
8. $h = (d + f) \tan \frac{1}{2} \beta$.

He discusses also the possible influence of an error on the part of the observer on the value of h, by means of the following differential derivatives from the preceding series, and

$$9.\ \cos (90^\circ + \alpha) = \sin \phi \sin \delta + \cos \phi \cos \delta \cos t.$$
$$10.\ t = \mathrm{T} - g,$$

where g is the correction to be applied to T, the mean time to convert it into t the true time.

Differential derivatives :

$$1.\ dh = \frac{r \sin \beta \, d\beta}{\cos^2 \beta}.$$

$$2.\ \frac{d\beta}{d\zeta} = \frac{(\cos \alpha - 1)}{\cos^2 (\zeta - \alpha)} \cos^2 \beta.$$

$$3.\ \frac{d\beta}{d\alpha} = \frac{[1 - \sin \zeta \sin (\zeta - \alpha)]}{\cos^2 (\zeta = \alpha)} \cos^2 \beta.$$

---

[*] 'Die auffallenden Abenderscheinungen im Himmel im Juni und Juli, 1885.'

Whence we have

$$4.\ \frac{dh}{d\zeta} = \frac{(\cos \alpha - 1)}{\cos^2 (\zeta - \alpha)}\, r \sin \beta.$$

$$5.\ \frac{dh}{d\alpha} = \frac{[1 - \sin \zeta \sin (\zeta - \alpha)]}{\cos^2 (\zeta - \alpha)}\, r \sin \beta.$$

Also for the variation of h corresponding to a change in T

$$6.\ \frac{dh}{dt} = \frac{r . \cos \phi \cos \delta \sin (t - g) \sin \beta\, [1 - \sin \zeta \sin (\zeta - \alpha)]}{\cos^2 (\zeta - \alpha) . \cos \alpha}$$

and for the variation of α corresponding to change in T

$$7.\ \frac{d\alpha}{dt} = \frac{\cos \phi \cos \delta \sin (t - g)}{\cos \alpha}.$$

As an example we may quote the complete series of observations made on July 19th, at Steglitz, lat. 52°·47 N., long. 53°·346 E., from which the corresponding values for h are given by Herr Jesse[*] as follows :—

July 19th.

	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.
Time of observation.	8 40·6	8 46·1	8 54·4	9 5·2	9 13·3	9 17·4	9 24·3	9 29·6
ζ	−75·7°	−73·5°	−68·4°	−53·0°	−19·0°	0·0°	47·6°	60·0°
h, in feet ..	32,809	48,557	76,773	111,551	131,892	143,375	153,218	162,405

	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.
Time of observation.	9 34·1	9 42·1	9 50·0	9 57·9	10 2·0	10 8·1	10 10·4
ζ	67·0°	73·9°	76·2°	79·0°	80·2°	82·0°	82·8°
h, in feet .	163,389	171,263	187,340	192,917	194,885	196,854	194,229

With this series the following values are derived for $\frac{dh}{d\zeta}$, $\frac{dh}{d\alpha}$, and $\frac{dh}{dt}$, in feet[†] :—

ζ	−75·7°	−68·4°	−19·0°	0·0°	47·6°	67·0°	76·2°	82·8°
$\frac{dh}{d\zeta}$ for 1° =	−693	−1,046	−295	−295	−660	−1804	−4490	−9510
$\frac{dh}{d\alpha}$ for 1° =	+26,480	+39,897	+43,013	+43,144	+39,468	+35,957	+33,503	+28,550
$\frac{dh}{dt}$ for 1′ =	2950	4268	4268	4170	3676	3212	2718	2036

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[*] The figures originally in kilometres are converted into English feet.

[†] Originally in kilometres.

From which it is evident that, for a small error in ζ, the error in h is greatest near the horizon ; that, for a small error in t, the error in h is greatest for observations near the zenith ; and that, in both cases, the errors are not very large except near these limiting positions.

These are the corrections for the height deduced from the primary glow, on the hypothesis of a first reflection, which is the only case considered by Herr JESSE.

The corrections for the secondary glow, on the hypothesis of two reflections, which is the most frequent case in Table I., would be smaller than those for the primary ; but $\frac{dh}{d\zeta}$ would still be large enough near the horizon to account for part of the differences shown in the heights at different places in the same months, which are referred to later on.

Since, in observations such as those included in Table I., many other possible causes of discrepancy exist besides those due to personal errors, such as variation of brilliancy, nature of locality and horizon, haze near the ground, &c., we have not considered it necessary to find the values for $\frac{dh}{d\zeta}$ or $\frac{dh}{dt}$, but have contented ourselves with deducing general means, which give us an approximate idea of the average height of the stratum.

TABLE I.

Height of the Stratum which produced the Glows at Sunrise and Sunset in 1883–4, computed by the writer.

Date.	Locality.	Latitude.	Duration of Primary in minutes.	Duration of Secondary in minutes.	Value of α (solar depression).	Formula employed.	Height above sea level from—		Sunrise = R. Sunset = S.
							Primary.	Secondary.	
1883.							feet.	feet.	
(48) Aug. 27 . .	Ship *Anerley*, 92 English miles N.E. of Krakatoa.	5° S.	. .	90	21° 22′	(7)	. .	121,550	S
(49) Aug. 27 . .	Rodriguez	19° 40′ S.	. .	75	18° 13′	(7)	. .	86,324	S
(50) Aug. 28 . .	Seychelles	4° 17′ S.	43	. .	11° 16′	(6)	98,088	. .	S
(51) Aug. 30 . .	St. Helena	15° 55′ S.	. .	† 120 ?	28° 55′	(7)	. .	[219,320]	R
(52) Sept. 2 . .	Venezuela	10° N.	. .	† 113 ?	25° 50′	(7)	. .	[173,850]	S
(53) Sept. 4 .	Ceylon	7° N.	. .	75	16° 51′	(7)	. .	73,715	S
(54) Sept. 5 . .	Honolulu	21° 18′ N.	. .	74	15° 13′	(7)	. .	59,884	S
(55) Sept. 6 . .	Ship *Carola*	4° 8′ S.	. .	90	20° 36′	(7)	. .	109,980	S
(56) Sept. 10 . .	Jaffna	9° 40′ N.	. .	75	17° 21′	(7)	. .	77.935	S
(57) Sept. 12 . .	Muscat	23° 37′ N.	. .	† 120 ?	25° 47′	(7)	. .	[173,850]	S
(55) Sept. 14 . .	Ship *Ida*	15° 12′ S.		75	17° 24′	(7)	. .	78,728	S
(55) Oct. 19 . .	Fort Yuma	32° 40′ N.	. .	90	20° 28′	(7)	. .	108,720	S
(59) Oct. 8	Binninag (Himalaya)	30° N.	. .	80	17° 5′	(7)	. .	75,580	S
(60) Oct. generally	Mauritius	20° 8′ S.	. .	75	18° 11′	(7)	. .	85,494	S
(55) Oct. 25 . .	Iquique	20° 12′ S.	. .	65	15° 5′	(7)	. .	58,964	S
(62) Nov. 23 .	Victoria (British Columbia) . .	49° N.	. .	120	18° 51′	(7)	. .	91,967	S
(63) Nov. 27 . .	Louvain	50° 53′ N.	43	92	6° 41′—13° 21′	(6) (7)	35,400	46,025	S
(64) Nov. 28 . .	Brunswick	52° 16′ N.	. .	120	16° 29′	(7)	. .	70,477	S
(65) Nov. 30 . .	Christiania	59° 54′ N.	. .	184	* 19° 31′	(7)	. .	98,970	S
(66) Nov. 29 . .	Laibach	46° 4′ N.	. .	120	20° 6′	(7)	. .	105,020	S
(67) ,, . .	Worcester	52° 11′ N.	. .	128	17° 42′	(7)	. .	84,118	S
(68) ,, . .	Ischl	47° 4′ N.	. .	98	15° 47′	(7)	. .	64,592	S
(69) Nov. 30 . .	Frauenfeld	47° 33′ N.	. .	112	20° 20′	(7)	. .	107,480	S
(70) Nov. generally	Mauritius	20° 8′ S.	40	76	10° 24′—17° 41′	(6) (7)	86,320	80,862	?
(71) ,, . .	Serra da Estrella (1441 metres above sea level).	40° 20′ N.	. .	120	21 46′	(7)	. .	122,900	S
(72) Nov. and Dec.	Tokio	35° 40′ N.	50	90	10° 40′—17° 45′	(6) (7)	90,825	81,940	S
(73) Dec. 1	Nice	43° 42′ N.	55	90	10 30 —15° 38′	(6) (7)	87,719	63,636	S
(74) ,, ...	Marburg	50° 48′ N.	. .	100	14° 7′	(7)	. .	51,864	S
(75) ,, ...	Orange	44° 7′ N.	. .	120	20° 11′	(7)	. .	106,250	S
(76) ,, ...	Freiburg	47° 59′ N.	. .	130	19° 39′	(7)	. .	100,160	S
(77) ,, ...	Constantinople	41° N.	. .	90	14° 48′	(7)	. .	56,247	S
(78) ,, ...	Gmünden	47° 56′ N.	. .	105	15° 52′	(7)	. .	65,555	S

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* According to M. Thirion, $\alpha = 21° 16' - 1° 45' = 19° 31$.

† These three observations give values so much in excess of most of the others that we have provisionally treated them as doubtful.

TABLE I.—*continued.*

Date.	Locality.	Latitude.	Duration of Primary in minutes.	Duration of Secondary in minutes.	Value of a (solar depression).	Formula employed.	Height above sea level from— Primary.	Height above sea level from— Secondary.	Sunrise = R. Sunset = S.
1883.							feet.	feet.	
(79) Dec. 2.. ..	Valence..	44° 55′ N.	..	105	17° 21′	(7)	..	77,672	S
(80) ,, ...	Madrid	40° 24′ N.	(1) 36	..	$\theta=45^\circ\quad\beta=4^\circ$ $a=4^\circ\,9'\ x=R\tan\beta\tan\frac{\beta}{2}$		51,000		S
			(2)..	111	16° 50′	(7)	..	73,517	S
(81) ,, ...	Vienna	48° 13′ N.	..	85	12° 24′	(7)	..	39,780	S
(71) Dec. 3.. ..	Lisbon	38° 42′ N.	(1) 28	..	$\theta=60^\circ\quad\beta=6^\circ\,7'$ $a=6^\circ\,17'\ x=R\tan\beta\tan\frac{\beta}{2}$		[119,270]*		S
			(2)..	100	18° 49′	(7)	..	91,967	S
(83) Dec. 2.. ..	Sydney	33° 51′ S.	..	100	15° 44′	(7)	..	64,592	S
(84) Dec. 4 . ..	Dalston	51° 28′ N.	35	..	$\theta=45^\circ\quad\beta=4^\circ\,41'$ $a=4^\circ\,52'$	..	69,622	..	R
(85) Dec. generally	Mauritius	20° 8′ S.	38	77	7° 47′ 15° 11′	(6) (7)	47,864	59,885	?
(80) Dec. 4.. ..	Madrid	40° 24′ N.	51	101	8° 54′ 16° 17′	(6) (7)	62,924	68,487	S
(66) Dec. 5.. ..	Laibach..	46° 4′ N.	50	..	8° 24′	(6)	56,247	..	S
			At max.	[80]	12° 49′ (6) $x=R\tan\frac{a}{3}\tan\frac{a}{6}$		58,052	..	S S
(88) Dec. 9.. ..	Paris	48° 50 N.	..	103	14° 32′	(7)	..	54,472	S
(89) Dec. 11 ..	Salthrop	53° N.	58	118	7° 20′ 14° 54′	(6) (7)	42,846	57,146	S
(90) Dec. 12 ..	Richmond	51° 27 N.	29	..	$\theta=60^\circ\quad\beta=4^\circ\,41'$ $a=4^\circ\,49'\ x=R\tan\beta\tan\frac{\beta}{2}$		70,297		
(55) Dec. 16 ..	Ship *Magdalena*	49° 3′ N.	..	105	13° 54′	(7)	..	50,160	S
(92) ,, ..	Stonyhurst	54° N.	..	110	12° 53′	(7)	..	41,871	S
Dec. 23 ..	Capetown	33° 56′ S.	..	80	12° 10′	(7)	..	38,294	S
(83) Dec. 20 ..	Sydney	33° 51′ S.	..	84	13° 24′	(7)	..	46,025	S
Dec. 25 ..	Sydney	33° 51′ S.	48	98	8° 15′ 15° 12′	(6) (7)	53,814	59,884	S
(99) Dec. 18 ..	Berlin	52° 30′ N.	64	101	7° 35′ 12° 00′	(6) (7)	45,420	38,640	S
(95) Dec. 25 ..	Dublin	53° 25′ N.	..	108	12° 30′	(7)	..	40,537	S
(96) Dec. 20 ..	Eimsbüttel	53° 33′ N.	..	128	15° 56′	(7)	..	65,555	S
(95) ,, ..	Dublin	53° 25′ N.	..	120	14° 11′	(7)	..	51,864	S
(98) ,, ..	Old Derrig, Co. Carlow, Ireland	52° 45′ N.	..	..	13° 30′	(7)	..	46,838	S
(98) ,, ..	Dunsink, Ireland	53° 23′ N.	..	..	15° 6′	(7)	..	58,965	S
(101) Dec. generally	Vittoria..	42° 47′ N.	..	110	17° 32′	(7)	..	79,791	S
1884.									
(102) Jan. 2.. ..	Flensburg	54° 47′ N.	70	..	7° 30′	(6)	44,620	..	S
(103) Jan. 3.. ..	Hamburg	53° 33′ N.	..	80	13° 45′	(7)	..	49,318	R
(104) Jan. 4.. ..	Lesina	43° 10′ N.	56	100	8° 25′ 15° 26′	(6) (7)	56,247	61,746	S
(105) Jan. 10 ..	Morges	46° 29′ N.	..	110	15° 9′	(7)	..	58,965	S

* Omitted in computing means.

In the Table II. which follows, the observations were made at one place (Richmond) by one observer (the Hon. F. A. Rollo Russell), the heights being calculated by means of the preceding formulæ. In Table III. the heights are calculated by Herr Jesse, from observations made near Berlin.

TABLE II.

Height of the Stratum which produced the Glows at Sunrise and Sunset, in 1883–4.

Computed by the writer, from observations by the Hon. F. A. Rollo Russell, at Richmond, Surrey, lat. 51° 27′ N.

Date.	Duration in Minutes from Sunset or to Sunrise.			Corresponding Values of α.			Height in Feet above Sea-Level.		
	(1.) Edge of Primary crossing Zenith.	(2.) Primary on Horizon.	(3.) Secondary on Horizon.	(1.)	(2.)	(3.)	(1.)	(2.)	(3.)
1883.									
Nov. 9, S. ..	37	69	100	5° 14′	10° 4′	13° 39′	87,438	80,862	48,485
Nov. 10, S. ..	..	53	..	..	7° 25′	..	..	43,630	
Nov. 26, S. .	..	55	..	..	7° 4′	..	..	39,780	
Nov. 28, S. ..	35	75	[85] ?	4° 50′	10° 5′	10° 49′	74,545	80,862	[33,305]?
Dec. 4, R. ..	36	57	105	4° 58′	7° 4′	13° 47′	78,728	39,780	49,318
Dec. 4, S. ...	34	..	..	4° 36′	..	..	67,500		
Dec. 5, R. ..	39	56	106	5° 0′	7° 32′	13° 47′	79,790	45,220	49,318
Dec. 6, R. ..	..	54	102	..	6° 55′	13° 6′	..	37,740	44,422
Dec. 11, R. ..	37	53	..	4° 42′	6° 44′	..	70,477	36,113	
Dec. 11, S. ..	34	66	104	4° 18′	8° 32′	13° 17′	58,965	58,052	46,131
Dec. 15, S. ..	..	..	101	..	..	12° 49′	..	..	42,846
Dec. 17, S. ..	..	56	..	..	7° 20′	..	..	42,840	
Dec. 19, S. ..	..	51	..	..	6° 44′	..	..	36,113	
Dec. 22, R. ..	..	..	104	..	..	13° 15′	..	..	45,422
Dec. 23, S. ..	39	61	..	4 54	8° 0′	..	76,622	51,000	
Jan. 23, S. ..	29 (about)	52	..	3° 34′	7° 26′	..	40,538	43,828	
Jan. 28, S. ..	24 (about)	46	..	3° 10′	6° 20′	..	31,940	35,315	

TABLE III.

Height of the Stratum which produced the Glows at Sunrise and Sunset in 1883–4 (*at Berlin*).

From observations at different angles by Herr Otto Jesse ('Meteorologische Zeitschrift,' 1884).

Date.	Duration in Minutes.	Angle *a*.	Height in Feet.*
1883.			
December 18	43	3°	40,354
"	48	2°	36,080
"	54	1°	44,291
1884.			
January 1	25	80°	26,896
"	35	19°	44,291
"	39	10°	51,508
"	42	6°	50,196
January 2	34	20°	45,931
"	35	15°	46,587
January 3	33	13°	38,048
February 17	34	10°	47,899
March 6 (Sunrise)	31	10°	34,768
"	29	23° ·5	32,144
"	25	19°	23,616
" (Sunset)	32	10°	37,072
"	38·5	4°	40,352
		Mean Height	.. 40,002

In order to see whether any secular changes occurred in the mean height of the stratum, we have arranged the figures in all the three foregoing tables in groups of monthly means, as follows :—

TABLE I. (a).

Mean Height of the Glow-causing Stratum from—

Period.	(1.)	No. of Observations.	(2.)	No. of Observations.
1883.	feet.		feet.	
August 27 to 30	98,088	1	142,398 (?)	(3)
Ditto, omitting August 30	..	..	103,937	2
September 2 to 14	..	..	106,848 (?)	(7)
Ditto, omitting September 2 and 12	..	..	80,048	5
October 8 to 25, and generally	..	..	82,190	4
November..	70,848	3	86,759	11
December	66,234	11	61,828	28
1884.				
January 2 to 10	50,434	2	56,676	3
True means, August 27 to January 10 (excluding the doubtful cases).	67,063	17	71,563	53
General mean of primary and secondary for the whole period.	..	..	70,470	70

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* Originally given in kilometres.

The means for Mr. RUSSELL's observations are as follows :—

TABLE II. (A).

Height of the Glow-causing Stratum from—

Mean of	(1.) Zenithal Passage of ulterior Margin of Glow.	No. of Observations.	(2.) Primary on Horizon.	No. of Observations.	(3.) Secondary on Horizon.	No. of Observations.
	feet.		feet.		feet	
November	80,991	2	61,283	4	48,485*	1
December..	72,013	6	43,357	8	46,242	6
January 23 and 28 ..	36,239	2	39,572	2	..	..
Whole period	66,654	10	47,938	14	46,563	7

Mean of all Three Modes of Observation.

	feet.
November	65,085
December	52,819
January	37,905
Whole period	53,665

The means of Herr JESSE's series are as follows :—

TABLE III. (A).

Height of Glow-causing Stratum in Feet.

Mean of	Number of Observations.	Height.
December, 1883	3	40,241
January, 1884	7	43,351
February, 1884	1	47,899
March, 1884	5	33,590
Whole period	16	40,002

Herr JESSE himself calculates the mean height from all his observations to be 17 kilometres, or 55,775 feet.

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* Leaving out the doubtful observation of November 28, which seems too short, compared with the others.

In addition to these we re-produce the following durations of the primary glow observed during January, 1884, by Captain von Possett, at Nice, which are similar to those of Jesse and Russell.*

	Minutes.		Minutes.
January 9	47	January 18	43
„ 10	46	„ 19	45
„ 11	48	„ 20	46
„ 12	43	„ 21	45
„ 13	53	„ 25	40
„ 15	42	„ 26	38
„ 16	43		

Dr. Albert Riggenbach† has more recently made some observations of the height of the atmospheric layers in which the purple glow successively makes its appearance. The table given represents the result of 76 measurements of the upper, and 35 of the under, limits of the purple light from the first glow.

As we are mainly concerned with the upper limit of the stratum, we shall notice only those measurements of the height when the glow is nearly on the horizon.

For zenith distance of the Sun.	Height above the Earth.	
°	kilometres.	feet.
95·5	18·6	61,025
96·0	20·7	67,914
96·5	21·4	70,211

The mean of these figures is 20·2 kilometres, or 66,274 feet, a height closely approximating to the mean we have found from our general list. The calculation is made by means of formulæ somewhat similar to those we have employed. The hypothesis of the cause of the glow given by the author, differs in some points from that which we have employed, but this does not affect the values given for the height from the first glow.

In judging of the results of the previous tables, regarding the height of the stratum which produced the glows, and its variation with respect to time and space, we must first notice the change in the latitude of the stations which are grouped for the different months. In the following Table are given (1) the mean latitude of the stations; (2) the corresponding mean heights from the primary and secondary observations; and (3) the mean of those which include, as well as exclude, the three doubtfully long observations in August and September.

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* 'Met. Zeitschrift,' August, 1884.

† In his pamphlet on the sun-glows and Bishop's Ring 1885, referred to in Section I. (E).

TABLE IV.

Period.	Number of Stations.	Mean Latitude.	Mean Height of Stratum from		Mean, including Doubtfuls.
			Primary.	Secondary.	
1883.		° ′	feet.	feet.	
August 27 to 30	4	11 12	98,088	103,937	142,398
September 2 to 14	7	12 59	..	80,048	106,848
October	4	25 45	..	82,190	
November..	*11	45 33	70,848	86,759	
December	*30	44 30	66,234	61,828	
1884.					
January	4	49 30	50,434	56,676	
	*59	Means ..	67,063	71,563	

The results from Mr. Russell's observations in Table II. for the latitude of Richmond, 51° 26′, give us mean heights for November and December somewhat similar to those in Table I., especially for the same latitudes; but there is a more marked falling off in January than appears in that Table.

It may also be noticed that the means for the entire months of October, November, and December, from the secondary for Mauritius calculated from Dr. Meldrum's observations, agree very fairly with the general means of the secondary in Table IV.,† thus:—

—	Mauritius.	Table IV.
	feet.	feet.
October	85,494	82,190
November	80,862	86,759
December	59,885	61,828

Three special observations at different angles at Madrid, Lisbon, and Richmond respectively, in December, yield a mean height of 80,189 feet, and one, on the hypothesis of the position of the sun when the glow was at a maximum, at Laibach, December 5th, gives a height of 58,052 feet.

The question of the greater heights yielded by the zenithal and angular observations, than by those when the sun's rays are tangential, will be discussed further on.

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* Including Tokio in each case.

† In taking the means these monthly observations have been regarded as only single observations.

The results from Herr Jesse's calculations, in Table III., are very similar to those we have derived from Mr. Russell's observations of the setting of the primary in December and January; but there is no falling off similar to that which appears in Mr. Russell's list at the end of January.

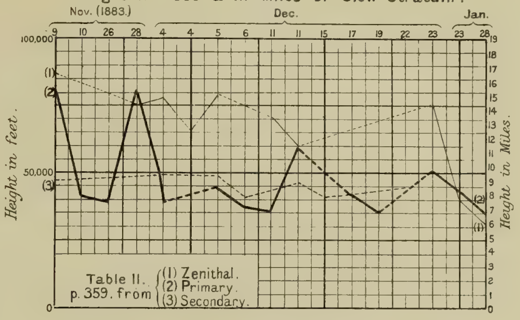
Now, a first glance at Table IV. leads us to the preliminary conclusion that there was a general descent everywhere of the mean height of the stratum, as measured by the duration of the glows from its first appearance on August 27th, 1883, to the middle of January, 1884, but a glance at Table I. shows that there are considerable differences between the individual observations. Before, however, propounding this inference in the form of a legitimate conclusion from the results of Table IV., we must examine the following points :—(I.) Whether the apparent decrease in the height of the stratum was due simply to the change of latitude, either because (*a*) the stratum was actually higher near the equator and lower near the poles; or (*b*) because the durations in the tropics would tend to give higher and more correct values than those in higher latitudes. (II.) The relation of brilliancy to duration, and the circumstances which might affect either or both, independently of any change in the height of the glow-stratum. (III.) How near an approximation the formula gives to the absolute height of the glow-causing material, its upper and lower limits, and their relation to the apparent decrease in the level of the entire stratum.

Regarding I. (*a*), it might seem at first to be borne out by Table IV., but, on closer examination, we see that there was evidently an apparent decline in the height of the stratum, independently of the change in latitude. Between November and December the decline occurs in spite of a small decrease of latitude; while from November to January, with an increase of only 4° in latitude, the heights diminish from the primary by 20,000 feet, and from the secondary by 30,000. Again, corresponding to the large increase in latitude between September and October, there is no correspondingly large decrease in the height of the stratum. Moreover, in one case at least, we have positive evidence of the decline in level at a tropical station, Mauritius, to about the same level in December, as that given by extra-tropical stations; the observer, Dr. C. Meldrum, F.R.S., being one in whom every confidence can be placed.

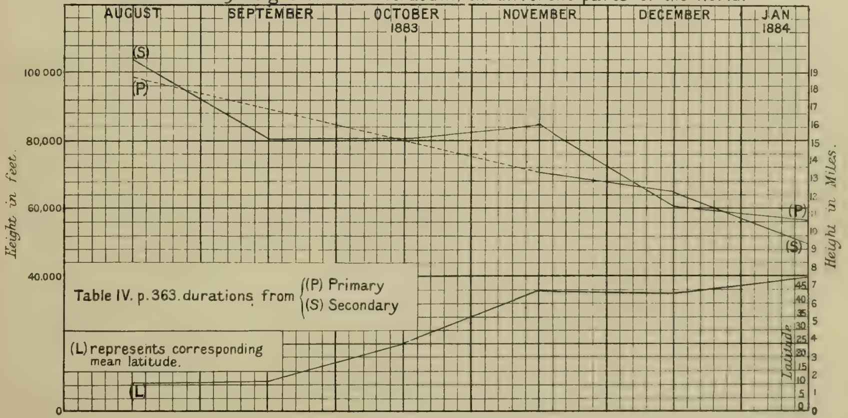
Month.	Duration of Primary Glow in Minutes.	Duration of Secondary Glow in Minutes.	Height of Stratum in Feet from	
			Primary.	Secondary.
October	..	75	..	85,494
November	40	76	86,320	80,862
December	38	77	47,864	59,885

CURVES ILLUSTRATIVE OF ALTITUDE OF GLOW STRATUM.

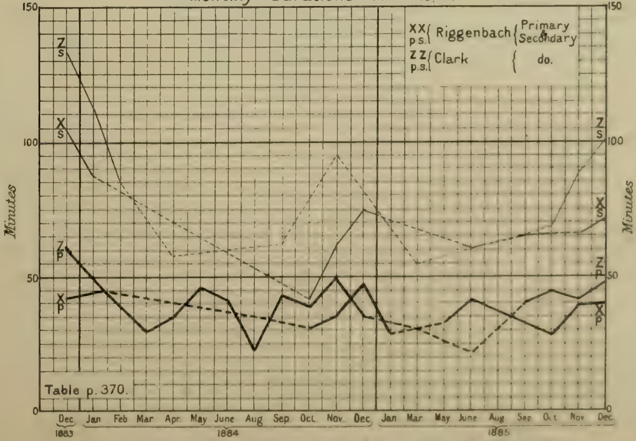
Height in Feet & in Miles of Glow Stratum.



Mean Monthly height of Glow Stratum, in different parts of the World.



Monthly Durations of Glow.



Dotted lines indicate discontinuity between their limiting points.

Malby & Sons Lith.

To supply the lacuna in October from the primary, we may perhaps add the height from a duration of the primary glow in the neighbouring Seychelles, giving 98,088 feet. Professor Riccò found (in his Summary quoted above) the heights descend from 27 kilometres (88,584 feet) on December 3rd, to 12 kilometres (39,371 feet) on February 5th.

At Sydney, from observations by Mr. Hargrave, the height on December 3rd = 64,592 feet, and on December 20th = 46,025 feet; and from Mr. Russell's series at Richmond it is evident that there was a progressive decline in the height from November onwards. In this case there was a specially marked falling off towards the end of January, which appears equally noticeable in other observations. In fact, after February 2nd, Mr. Russell's observations stopped, and for the next few months the glows decreased everywhere so much in brilliancy and duration that they ceased to attract public attention. On the whole, therefore, there seems to have been a progressive change in the apparent height of the stratum everywhere, independently of the variation of latitude. This change, however, occurs too irregularly, to admit of our determining its actual amount for the period embraced by Table IV., and we are thus unable to say precisely how much was due to progress of time, and how much to an initial (and perhaps permanently) greater height of the stratum near the equator than in higher latitudes. The entire change in the apparent level, from August 27th to December, appears to have been from about 8,000 to 10,000 feet per month.

I. (*b*). If the durations in the tropical zone had been uniformly the same as those in high latitudes, we might have supposed that, owing to a want of transparency of the atmosphere in the latter, the durations were too short, but in most cases the proper relations between the two were preserved; the durations in the tropics being, primary, 40 minutes; secondary, 75 minutes;* and in the extra-tropics, primary, 55 to 60 minutes; and secondary, 120 minutes. The sunsets were reported to be more lurid in the tropics, but there is nothing to prove that they were absolutely more brilliant than those in high latitudes.

II. The question as to the circumstances which might, or did, affect the character and duration of the twilight glows, has been studied amongst others by Professor H. A. Hazen,† Professor G. H. Stone,‡ Mr. J. Edmund Clark,§ Professor Riccò,|| Mr. C. L. Wragge,¶ and Professor Kiessling.**

Professor Stone found that the twilight glows and corona varied inversely, the

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* Excluding the three doubtful cases.

† See Section VI.

‡ See Section I (e).

§ 2nd 'Warner Prize Essay.'

|| 'Riassunto, &c., R. Accademia dei Lincei.'

¶ 'English Mechanic,' September 12, 1884.

** "Über die Entstehung des zweiten Purpurlichtes," etc. 'Das Wetter,' September, 1885.

conditions favourable for the one being dry weather, and for the other a cold wet storm. This agrees with the evidence given by all the others, which may be summarized as follows :—

	Attendant conditions.
Brilliant twilight glows.	(1.) High barometer.
	(2.) Low temperature at the earth's surface.

To which Mr. J. Edmund Clark adds the following, which are naturally connected with the foregoing, viz. :—

(3.) Decidedly dry days.
(4.) Slight rain-band.

Mr. Clark's observations extend over a period of two years.

Professor Riccò, from a very careful comparison, extending over several months, found that when the glow was accompanied by a strongly-defined brownish arc at sunset, which latter probably represented the last stage of the corona, the humidity of the lower atmosphere was above the average. This result would, therefore, agree with that of Professor Stone, in showing that the condition favourable to the development of the corona was a humid and, therefore, dustless lower atmosphere.

Professor Kiessling, from a detailed comparison of conditions attending ordinary twilight phenomena, as well as the extraordinary series under discussion, arrives at conclusions similar to those already quoted, but pursues the investigation until he reaches a condition which usually accompanies high barometric areas in the colder part of the year, and to the influence of which, on that of a superior layer of cloud-haze, he attributes, through the medium of diffraction, the entire phenomenon, exclusive of the second after-glow.

This condition is the occurrence of a warm upper stratum of air over a surface stratum of cold and relatively damper air ; and the formation of intense twilight tints is explained by him to be due to diffraction through a horizontal layer of homogeneous mist particles, which he shows experimentally would be formed at the upper boundary of this warm current with the lofty cloud-haze. By a comparison of various observations, especially in Switzerland, Professor Kiessling finds that ordinary brilliant sun*rises* are associated with an anomalous vertical distribution of temperature over the Eastern Alps ; and, similarly, that brilliant sun*sets* are associated with corresponding vertical temperature anomalies over the Western Alps ; the anomalies in each case indicating unusual warmth in the upper regions.*

A further comparison, made by Captain Bardua, of observations at Leipsic and

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* "Über die Entstehung des zweiten Purpurlichtes," etc., 'Das Wetter,' vol. ii., 1885, p. 161.

Oberwiesenthal in 1877, 1879, 1880, and 1881, on occasions when the morning or evening colouring was conspicuous, and on November 29th and 30th, 1883, when the first remarkable glows of the present series were seen, shows the same marked features of unusual warmth in the upper regions, and unusual cold and accompanying relative humidity in the air near the surface.

Following this, we have a comparison by Professor KIESSLING himself of the temperature and humidity conditions between eight of the principal high and low stations in Europe during the period November 27th to December 2nd, 1883, when the glows were most brilliant and reached their longest duration over Europe, leading to the same conclusion, which may be enunciated in the following words :—

"The conditions which generally accompany ordinarily fine twilight phenomena, as well as the maximum phases of the extraordinary series which began in November, 1883, in the extra-tropics, involve the interposition, between the observer and the sun, of a warm (*absolutely moist if relatively dry*) upper stratum overlying a cold, and relatively moister, under stratum of atmosphere, together with the presence, immediately above the warm stratum of a layer of cirrus-cloud or haze."

Such conditions tend to be partially produced over every extensive area of high barometer, especially in the winter, and it seems probable that we have here a proximate explanation of the fact noticed by Dr. HELLMANN,* in an article in which reference is made to his own observations on the duration of twilight in Spain in 1876 ; from which it is inferred that the angle α of the sun's depression at the end of the astronomical twilight is about 1° greater in the winter than in the summer, and which he thence infers to be due to the greater humidity of the air in the former than in the latter season.

By greater humidity, Dr. HELLMANN means such as was observed at the earth's surface ; and that this might co-exist with a warm and relatively dry condition of the upper air, is a fact well known to be theoretically probable, and practically present during the prevalence of anti-cyclonic conditions in winter.

In confirmation of the same idea regarding the apparent part played by relative humidity in lengthening ordinary twilight, Dr. HELLMANN quotes the results obtained by Prof. J. SCHMIDT at Athens, where the wet and dry seasons are similar, and also the following series of morning and evening observations made by Captain PUJAZON, of the San Fernando Observatory :—

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* "Beobachtungen über die Dämmerung," 'Zeitschr. für Met.,' Bd. ix., 1884, p. 57.

PROFESSOR J. SCHMIDT.

1877.	Value of *a* (solar depression) at the end of Twilight.	Relative Humidity.
	° ′	
March 6, morn	18 15	72
,, 6, even	15 51	55
,, 7, morn	17 51	80
,, 7, even	16 3	61
,, 8, morn	17 15	82
,, 8, even	15 15	77
,, 12, morn	19 13	84
,, 12, even	15 24	61
,, 13, morn	19 25	83
,, 13, even	15 26	74
,, 14, morn	18 13	88
,, 14, even	15 50	68

and

CAPTAIN PUJAZON.

1877.	Value of *a*.	
	Morning.	Evening.
	° ′	° ′
March (11 days)	17 57	15 42
April (1 day)	..	16 17
May (4 days)	17 49	14 56
June (2 days)	17 38	..
August (3 days)	17 30	14 38
October (10 days)	..	16 30
November (2 days)	..	16 16
Means	17 43	15 43
Mean difference	2°	

These last results seem to show either that all conditions which tend to produce greater humidity near the surface, favour the prolongation of twilight, or else that in the morning the condition of the air generally approximates to that in a winter anti-cyclone.

In the present series no material difference has been detected between the values of *a* for morning and evening glows. Two other factors, mentioned by Dr. HELLMANN, which affect the value of *a* for ordinary twilight, and, therefore, possibly for the extraordinary glows, are : (1) that it is greater in higher than in lower latitudes ; and (2) greater in dry continental regions, than in those which border the oceans.*

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* Probably because in the former regions anti-cyclonic conditions are more prevalent than in the latter.

Without pursuing any further the interesting points thus raised, it is plain that certain factors exist which might, and did, affect the brilliancy and duration of the glows, depending partly on (A) the time of day; (B) the latitude; (C) time of the year; and (D) on the occurrence of cyclonic or anti-cyclonic conditions, over the area at the time of observation.

(A) Would not seriously affect the values deduced from Table I., since they were mostly sunsets; (B) is very small; (C) would hardly sensibly affect the results taken in latitudes so different and for so short a period, though the fact of a normal winter maximum would tend to exaggerate the difference in the real height of the stratum between August and December; but (D) might account for the intermittent character of the glows, especially when compared with the nearly constant appearance of the "day-glow" or corona. This last factor is, however, merely an auxiliary, the real seat of the phenomenon lying, as Professor KIESSLING says, in the peculiar lofty delicate cloud-haze which was noticed everywhere to accompany the unusual twilight glows of 1883–4; just as ordinary lofty cirrus appears to produce ordinary brilliant twilight glows. The explanation given by Professor KIESSLING of the production of the primary glow in the present series, *entirely* by diffraction from the plane of intersection of the cloud-haze with the warm layer of air which is assumed to reach its level, and of the secondary alone by reflection of the primary, is not so probable as that which attributes both the primary and the secondary glows to the reflection by the stratum of rays, already deprived of their blue components by diffraction, through the haze and the lower atmosphere.

How far both the brilliancy and the duration were affected *pari passu*, it is difficult to say; but, on the whole, it may be said that brilliancy and duration were closely connected; so that conditions which would affect the one would necessarily have some influence on the other.

In judging, therefore, of the actual rate of descent of the stratum, as calculated from the durations, account must be taken of any intermittent recurrences of brilliancy and duration after its apparent rapid decline at the end of January, 1884, and of the character of its prolongation after this date.

For the purpose of exhibiting these features, we shall here reproduce, in a condensed form, the tail end of the Hon. ROLLO RUSSELL'S series, and those of three other observers, which carry on the observations up to the latest date.

The other observers are Dr. RIGGENBACH, Basle;* Professor RICCÒ, Palermo;† Mr. J. E. CLARK, York.‡ Their observations will be denoted by the letters X. Y. Z. respectively.

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* Pamphlet published at Basle, 1886.

† 'Quarterly Journal Royal Met. Society,' January, 1886.

‡ 2nd 'Warner Prize Essay.'

The latter part of Mr. Russell's *Observations.*

——	Duration of Primary Glow* in Minutes.	Value of *a*.	Ulterior edge of Primary crossed Zenith after Sunset.	*a*.	Duration of Secondary Glow in Minutes.	
1883.		° ′		° ′		
December 23	61	8 0	39	4 54	91	*a* declines proportionally, as in primary.
1884.						
January 23	52	7 26	29	3 34	80	
January 24	..	..	..	..	..	
January 28	46	6 20	24	3 10	72	
February 2	42	..	21			

Riggenbach, Riccò, and Clark's *Observations.*

——	Primary Glow—Mean Monthly Duration in Minutes.				Secondary Glow—Mean Monthly Duration in Minutes.			
	X.	Corresponding Value of *a*.	Y.	Z.	X.	*a*.	Y.	Z.
1883.		° ′				° ′		
December ..	43	7 18	..	61	105	17 0	..	134 (3)
1884.								
January .	45	7 12	45 (2)†	48 (6)	88·5	14 0	97 (2)	113 (5)
February.. ..	..	.	52 (1)	39 (3)	..	..	97 1)	85 (1)
March	..	..	35 (2)	30 (1)	..	..	43 (?)	
April	..	..	36 (3)	36 (4)	..	..	50 (?)	58 (1)
May	38	5 42	..	47 (2)				
June	..	..	..	43 (2)				
August	..	..	..	23 (1)				
September ..	..	..	..	44 (5)	..	..	..	63 (2)
October	32	5 54	..	39 (2)	41	7 30		
November ..	36	6 12	..	50 (2)	62	10 24	..	95 (1)
December ..	49	7 42	..	35 (1)	75	11 48		
1885.								
January	29	4 54						
March	..	..	..	30 (2)	..	..	..	54 (1)
May	33	5 6						
June	43	6 0	..	22 (2)	62·5	8 18		
August	36	6 12						
September ..	33	6 6	..	40 (1)	65	11 24		
October	27·5	5 12	..	44 (4)	..	..	..	68 (1)
November ..	39	6 42	..	43 (5)	65·5	10 18	..	88 (2)
December ..	40	6 18	..	49 (4)	72	11 18	..	102 (2)

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* In all these cases the value of *a* is given corrected for refraction.

† Bracketed numbers indicate the number of observations.

We supplement the foregoing table by the following means, derived from Professor Riccò's determinations of the intensities of the two glows on an arbitrary scale, 0—10 :—

Mean Intensity of Glows. Scale, 0—10.

——	Primary.	Number of Observations.	Secondary.	Number of Observations.
1883.				
December	8	(9)	8·2	(8)
1884.				
January	8	(5)	8	(5)
February	5·4	(10)	2·2	(9)
March	5·2	(5)	2·2	(4)
April	3·3	(14)	0·9	(13)

An examination of the foregoing tables leads to the conclusion that while the value of the duration of the primary glow was higher than usual in December, 1883, and January and February, 1884, and declined in brilliancy and duration (though not quite proportionally) until March, it yet often subsequently reached nearly the same duration as in December and January, and appears by no means to support the inference that that part of the stratum which was concerned in the production of the primary glow either descended at a constant rate or disappeared before December, 1885.

Regarding the secondary glow, the falling off in the durations is more marked, and the values do not appear to have again reached the same amount as in December, 1883, and January, 1884, though in December, 1884, they were not far off, according to Riggenbach, and in December, 1885, according to Clark.

In both primary and secondary glows the existence of a distinct maximum in the winter months is noticeable. If the glows all through the preceding list were of the same character as those which were seen at first, we should hardly be able to conclude anything definite as regards the changes in the stratum from the durations of either primary or secondary; but it is evident, both from Professor's Riccò's determinations of the intensity and from universal testimony, that the extraordinary brilliance of the glows in the last two months of 1883 and the first two or three of 1884 was never afterwards equalled. While, therefore, enough of the finest material remained in the higher regions to give feebler glows of nearly the same duration as at first, we must suppose that the larger particles, which would be more particularly effective in causing the secondary glow by reflection, sifted out in time by gravitation. The evidence from the section in which the "corona" is discussed, favours this view, since while the glows reached their extra-tropical maximum at the end of November, the corona did not reach its maximum, according to Professor RICCÒ, until April, 1884, by which time the secondary glows had, according to the same writer in the table quoted above, reached a decided minimum. The stratum, in fact, relieved of its grosser particles, had become more homogeneous, and reached its maximum capacity for diffraction.* Also, as the corona itself began to decline after this date, and disappeared altogether about the end of 1885 or beginning of 1886, we must believe that in time the finest particles gradually descended, and became mixed up with the lower atmospheric currents, and the stratum, thus losing both its initial horizontal character and its subsequent homogeneity, ultimately became unable to affect the sun's rays either by reflection or by diffraction.

Although, therefore, owing to the complexity of the conditions surrounding the question of brilliancy and duration of the glows, and the intermittent character of their apparent decline in duration after the winter of 1883–4, we are unable to derive any trustworthy quantitative estimate of the relative decline of the stratum as a whole, it appears probable, both from the fact that the durations would tend to give a maximum in the winter months, as well as from the fact that a progressive decline in brilliancy and duration was observed in the tropics between August and December, and the later appearance of the glows in the extra-tropics at a much reduced height (judging from durations), that the denser part of the materials causing the intensely brilliant earlier glows was initially in the tropics at a higher level than when it subsequently reached the extra-tropics; that, as time progressed, the denser part sifted out by gravitation to lower levels all over the world, and at a rate of between 8,000 feet and 10,000 feet per month; that the finest particles, which were left behind, remained suspended (as Professor STOKES's formula, applied to their size, estimated from the diameter of the corona—which, it must be remembered, reached its maximum in April, 1884, and was often measured after that date—shows was possible) for over two years not far below their original height, and were thus capable, in favourable circumstances, of affecting the prolongation, and in some measure the brilliancy, of ordinary twilight phenomena.

III. We have hitherto not touched upon the question of the absolute height of the stratum as measured from the durations, and the values of α. If the stratum be supposed to have been simply an extended sheet of no great vertical thickness, the question of upper, mean, and lower limits would not enter. If, however, as we must conclude, the stratum had not only a sensible depth, but was, to some extent, heterogeneous, and the grosser particles subsequently gravitated to lower levels, the question arises, from what part of the stratum did the reflection then proceed, and what approximation to the upper, mean, or lower height of the stratum do the durations afford us at different periods?

The approximation will depend mainly on the following conditions:—(1) On the

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* The brief appearance of the coloured sun likewise favours this view. See Section I. (c).

correctness of the hypothesis of the two glows which has been employed; (2) on the position of the region which reflected the tangential rays with respect to the inferior and superior limits of the stratum; and (3) on the accuracy of the determinations of the moment of disappearance or appearance of the glows.

(1) Has already been fully discussed in the first part of this section, and without further discussion we shall assume the hypothesis of two reflections for the secondary.

(2) Regarding this point there appears to be some difficulty, seeing that the results of our general table, and especially of Mr. RUSSELL's observations of the zenithal passage of the ulterior margin of the glow, as compared with the times of disappearance on the horizon, are directly contrary to those obtained by Herr JESSE in his article in the 'Met. Zeitschrift,' February, 1884, in which he infers theoretically, what his observations, on the whole, bear out practically, that the heights deduced from high-angle observations should be lower than those from horizon disappearances. In Mr. RUSSELL's series the heights given by the zenithal observations exceed those of the primary and secondary on the horizon by a mean value of about 20,000 feet. According to Herr JESSE, the reflection, when near the zenith, proceeds from a part of the stratum situated below its upper edge, and as the glow descends to the horizon it should proceed from points situated nearer the superior limit of the stratum.

The equation giving x the true height of the upper limit in terms of h, the apparent height is—

$$x=h+e\cos(\zeta-\gamma),$$

where ζ is the co-altitude, γ the geo-centric angle between the point where the reflected ray meets the top of the stratum and the observer's zenith, and e the distance measured along the reflected ray of the point in the stratum whence the reflection proceeds from the upper limit of the stratum. For January 1st, $e = 11{\cdot}6$ kilometres, or 38,058 feet, and by comparison

$$e=e_0+0{\cdot}237\,n \text{ (in kilometres)},$$

where n = number of days from January 1st and e_0 = value of e on January 1st. This would make e vanish on November 14th.

If Herr JESSE's theory be accepted, there seem to be only two causes which might combine to explain the discrepancy: The ulterior edge of the primary glow, when near the zenith, might, owing to contrast with the darkness beyond, have been visible up to its limit in the top edge of the stratum. The generally high values given by Mr. RUSSELL's figures when compared with those of Herr JESSE, which include mainly the point of maximum glow, favour this. The obscuration which any tangential rays, and especially those from the upper part of the stratum, would experience from their lengthened passage through the lower and grosser parts of the stratum, as well as through the lower atmosphere, which would tend not only to invert the law which would theoretically operate were there no atmosphere and a perfectly homogeneous stratum, but would cause the horizontal glow to proceed from the middle, or even lower, boundary of the stratum.

(3) This naturally brings us to the third point, viz., the accuracy of the determinations of the moments of appearance and disappearance, and their effect on the absolute heights. In a list comprising observations from so many different places and by observers of every kind, errors of all sorts are likely to arise. Some may have estimated too short and others too long, but the probabilities in observations of this kind are that the longer durations are more nearly correct. Against this we have the possibility of a tertiary glow, and also the tendency of the human mind to exaggerate, rather than to under-estimate, the duration of a remarkable phenomenon. The three values which stand out prominently from the rest in the tropics are those of St. Helena, Venezuela, and Muscat — places distant about 9°, 16°, and 29° respectively from the latitude of Krakatoa. On the hypothesis of a secondary glow, the values for the height corresponding to the solar depression at the time of disappearance on the horizon at these places exceed those of any others, either in the tropics or elsewhere, by more than 50,000 feet.

This is an excess of a very serious character, and as there does not seem to be any special reason for doubting the accuracy of these observations, we are led to conclude either that these values really represent the actual height within the tropics more nearly correctly than do the others, or that they represent tertiary glows produced by a reflection, on to the haze, of the light proceeding from the secondary glow.

In favour of (*a*) we have the height for the ejecta from Krakatoa estimated by Mr. VERBEEK, from the position in which certain blocks were found after the eruption, and which, assuming them to have been thrown up at an angle of 80°, must have been 164,040 feet (31 miles), and also some rather long durations in Spain and France.

In favour of (*b*) we have the comparative brevity and regularity of the durations of the primary, both in the tropics* and extra-tropics, together with the possibility of a tertiary glow where the material was dense and the atmosphere clear. Also, the ratios of the three principal values of the durations in the tropics and extra-tropics favour the same notion. Thus—

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* *E.g.*, Dr. MELDRUM's, 40 and 38 mins.

——	Primary.	Secondary.	Tertiary. (?)
	Minutes.	Minutes.	Minutes.
Tropics	40	75–80	120
Extra-tropics..	50–60	100–120	180

the ratios being 1 : 2 : 3.

The formula for the heights, on the hypothesis of a tertiary glow, and the assumption that it arose from a repeated reflection from the haze when the sun was illuminating one-half of the sky whence the subsequent reflected glows were derived, would be

$$h = \mathrm{R} \tan \frac{a}{10} \tan \frac{a}{5}.$$

Treating these three observations by this formula, we get the following results :—

	Glow stratum. Height in feet.
Muscat	84,118
Venezuela	85,217
St. Helena	106,250

These values appear to be more reasonable than those already obtained on the hypothesis of the secondary glow, and agree with the general means, as well as with the individual observations by Dr. MELDRUM.

Regarding the general question of the discrepancies between the values of the solar depression, especially at the end of the secondary glows, not only in different latitudes and by different observers, but by the same observer on different days, it is plain that these are due not merely to objective differences in the duration due to the action of the several factors which we have been considering, such as brilliancy, condition of the stratum, transparency of the lower air, geographical position of the place of observation, time of year, &c., but subjectively, or incidentally, to the character and fancy of the observers, some of whom were untrained.

The amount by which the heights deduced from the duration of the secondary glow on the horizon diverge from the monthly means is shown in the following table :—

—	No. of Observations.	Mean Excess.	Mean Defect.	Mean Range.
1883.		feet.	feet.	feet.
August	3	+ 17,613	– 17,613	35,226
September	7	+ 18,142	– 12,798	30,940
October	4	+ 15,428	– 14,417	29,845
November	11	+ 18,508	– 15,423	33,931
December	30	+ 17,630	– 11,101	28,731
1884.				
January	4	+ 7,358	– 3,679	11,037

True mean of mean ranges .. .. 29,349 feet.

It will be noticed that, with the exception of January, the ranges for each month are remarkably similar, though, as the heights diminished, they really increased relatively, and varied from 34 per cent. of the height in August to 46 per cent. in December.

Where one observer remained fixed, the range was not so great. From Mr. Russell's series, for example, the range was only 16 per cent. of the mean height in December.

If we consider this value to represent the variation in December due to daily changes of brilliancy or transparency, there remains 30 per cent. to be accounted for by other causes, including personal equations and errors of estimation.

As we have before said, the probability is in favour of the longer durations being the more nearly correct.

If, then, we add to the means already derived, the mean excess for each month which represents the effect of the longer durations, we shall probably get a closer approximation to the height of that part of the stratum which was effective in causing the glow when on the horizon (either the middle or upper part from the longer durations) than that which is represented by the means in Table IV.

Thus we get the following *:—

——	Number of Observations.	Height of Glow-Stratum for Secondary from Longest Durations.	Number of Observations.	Height of Glow-Stratum from Primary from Longest Durations.
1883.				
August	(2)	121,550		
September .. .	(5)	98,190		
October	(4)	97,117		
November .. .	(11)	105,267	(3)	88,522
December	(28)	78,261	(11)	86,727
1884.				
January..	(3)	64,024		
True means ..	..	87,996	..	87,112

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* Applying the same process to the primary, where it is possible.

If in the case of the longer durations the horizontal obscuration was a minimum, the preceding observations ought to give us some approximation to the upper limits of the stratum, owing to the operation of the theoretical law, by which reflection would tend to proceed from the higher parts of the stratum in proportion as the sun descended. For obvious reasons no approximation to the lower limits of the stratum can be given.

All we can say, therefore, is, that the middle or upper part of the haze which, mainly by its reflection of solar rays, caused the glows from August, 1883, to January, 1884, lay at an elevation of from 121,550 feet at starting, to 64,000 feet in January, 1884, with a probable error of about 15,000 feet, which, on the mean of all the observations, is equivalent to about 7½ minutes of time in the duration; an error quite within reasonable limits.

For comparison, we give the general results obtained by different persons and methods below :—

Observers.	Date.	Height of Glow-Stratum in feet.
Miss Annie Ley N. S. Shaler O. Jesse Dr. Galle P. Estrelle J. Aitken Meidinger } Mean	November and December, 1883 ..	57,222
Dr. Riggenbach..	November, 1883, onwards	66,264
Herr Jesse, 16 primary	December, January, February, March	41,270
Professor Riccò	December to April	57,414
Archibald (from 17 primary and 53 secondary in general list)	November, December, 1883; and January, 1884	true mean of all 70,226 true mean of longest durations 87,554
,, from Mr. Russell's 14 primary and 7 secondary	November, December, January ..	47,479

The means for individual months, and the general means from Table I., have already been given.

Since, according to Dr. Hellmann,[*] the angle of solar depression at the end of astronomical twilight is not a constant, but varies from 15° to 18°, it is not easy to say how far the astronomical twilight has been increased on the present occasion. That the duration of the glow has, however, considerably exceeded the ordinary twilight is manifest from the values of a in Table I., p. 357, where it will be seen that—

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[*] 'Zeitschrift für Met.,' February, 1884.

a lay between 17° and 18° in 8 cases.
" " 18° " 19° " 4 "
" " 19° " 20° " 2 "
" " 20° " 21° " 5 "
" " 21° " over " 5 "

As the latter half of astronomical white twilight is attributed to the reflection of light already received on to strata situated below the horizon,* we must infer that the lengthening of its duration, as well as its coloration, in the present case was not due to the material which caused the glows lying at greater heights than the particles, whether dust or vapour, which are ordinarily concerned in producing this phenomenon, but to its being present in greater quantity than is usual in the upper regions of the atmosphere.

We have in this section thus far confined our estimates of the height of the glow-stratum to those determined by means of the duration of the glows. We shall now advert to some actual measurements which were made of the height to which the smoke was seen to attain during both the minor and the major eruptions of Krakatoa in 1883.

Before alluding to these, it may be noticed that the height of the column of vapour from Vesuvius during great eruptions has been found to be between 23,000 and 26,000 feet.† In other words, it fully attains the height of the cirrus cloud which, according to MM. EKHOLM and HAGSTRÖM, averages 23,687 feet.‡

Then again we have the estimate made by Messrs. HOFFMANN and SCHULTZ, referred to in Section V., p. 396, of the height attained by the smoke column from Graham's Island in July, 1831, which was, at least, 20 kilometres = 13 miles = 65,618 feet.

Mr. WHYMPER remarks, concerning his observation of the eruption of Cotopaxi, from the slopes of Chimborazo, on July 3rd, 1880, already referred to in Section I. (C), that the column of smoke reached a height of 20,000 feet above the crater, which, added to the height of the latter, would make it altogether nearly 40,000 feet above sea-level.§

We are, therefore, prepared to find that during the eruptions of Krakatoa in 1883, and particularly in the grand one of August 27th (which appears to have exceeded in explosive force anything hitherto recorded of volcanic action), heights were attained considerably in excess of those which are attained during ordinary eruptions in Europe and America.

Thus, during the minor eruption of Krakatoa on May 20th, the *Elisabeth*, when

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* KAEMTZ, 'Meteorology,' translated by WALKER, p. 409.

† 'The Earth,' by E. RECLUS, p. 547.

‡ 'Mesures des Hauteurs et des Mouvements des Nuages,' p. 38.

§ Similarly Prof. RICCÒ says that during its last eruption Etna projected its column of vapour to a sea-level height of nearly 14 kilometres = 45,930 feet, or 35,000 feet above its crater.

in sight of the volcano, saw a column of vapour and ashes rise to a height of 11,000 metres, or 36,090 feet.*

On August 26th, an observation was made by Captain THOMSON of the *Medea*, referring to which Mr. VERBEEK says :—"After the first explosion, a column of smoke was seen to rise, which, according to one measurement, attained a height of 17 miles; and, according to another, taken 3 hours after the detonation, a height of 21 miles. This latter value is considered less certain."

If we take the mean of these two observations, viz., 19 miles, or 100,320 feet, we may consider this to represent the inferior limit of the column of smoke which was afterwards ejected with far greater energy, especially at 5 hrs. 30 mins., 6 hrs. 44 mins., 9 hrs. 58 mins., and 10 hrs. 52 mins., on August 27th, the times, according to VERBEEK, of the most violent explosions.

In fact, if we are to judge by the distance at which the sounds of the latter explosions were heard, as well as by their effects as registered on the recording sheet of the gas-meter at Batavia, and more especially the grand one of 9 hrs. 58 mins., which appears to have registered itself on every recording barometer in the world; we should, perhaps, be not over the mark in estimating the height reached by some of the materials at from 50,000 to 75,000 feet higher than that measured on the 26th; say, 150,000 to 180,000 feet.

We are, therefore, prepared to accept Mr. VERBEEK's estimate of the height attained by some of the larger materials which were ejected during the later explosions from Krakatoa, and which were found at Katimbang, a distance of 30 miles from the volcano, to be, as before stated, 164,000 feet, or about 31 miles.

That some of the finer material may have reached even greater heights than this, during the most violent explosions, is not at all improbable.

The maximum height, excluding doubtful cases, of 121,550 feet for the haze in August, deduced in the preceding paragraphs, does not, therefore, appear to be an over-estimate.

One further line of proof may possibly be indicated by the proportion existing between the distances at which the sounds were heard in the minor and major eruptions, and the height actually reached by the smoke in the former, though it must be admitted to be, at best, a very uncertain and only approximate one.

Assuming the sonorous energy, as exhibited by the sounds, to vary with the eruptive energy by which the materials were ejected, the squares of the distance reached, or height attained, would equally represent the respective forms of energy.

Now, the greatest distance known to have been reached by the sounds in the May eruption was Singapore,† which is 522 English miles from Krakatoa; while the greatest distance to which the August eruption penetrated, was Rodriguez, about 3,000 English miles distant, the ratio being 6 : 1.

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* 'Jahresbericht der deutschen geographischen Gesellschaft,' Berlin, 1884.

† 'Krakatau,' p. 30.

Multiplying the height calculated from the *Elisabeth* by this ratio, we get, on this assumption, 216,540 feet (41 miles) for the height attained during the August eruption. This is probably a maximum.

Taking all the facts together it does not seem improbable that while some of the material was projected to a height of 160,000 feet or more, the main mass of it was certainly as high as 120,000 feet at starting, and afterwards descended in the extra-tropics to the more moderate but still lofty heights, which we have estimated from the duration of the twilight glows.

The estimates of 100 miles by Messrs. Bishop and J. E. Clark,* on purely hypothetical data, are far above those obtained as the results of the present investigation.

Summary of Part IV., Section IV.

The results of the present section may be summarised as follows:—

(1.) That in the brilliant glows which began in the tropics after the eruption of Krakatoa on August 26th and 27th there is distinct evidence of a primary glow caused by the direct rays of the sun, and of a secondary glow succeeding this, and due to reflection of the primary glow by the same stratum. That these primary and secondary glows correspond to the first and second crepuscular spaces of ordinary twilight; and that the main difference between the secondary of the present series and the ordinary second crepuscular space is that the former was coloured, whereas the ordinary second twilight is white, and seen only from high altitudes or in peculiarly favourable circumstances.

(2.) That the glow-causing material appeared suddenly and at about its greatest height, at first in the Indian Ocean, near Krakatoa, and for some degrees north and south of its parallel throughout the tropical zone; that it subsequently spread into the extra-tropics, as is fully described in Section II.; and that, partly owing to lapse of time and partly to change of locality, it appeared at a lessened altitude.

(3.) That the height of the upper or middle part of the stratum, as deduced mainly from the particles which were large enough to reflect, progressively diminished from 121,000 feet in August to about 64,000 feet in January, 1884, the inferior limits being more probably those given in Table I.(A), p. 360, viz., from 104,000 feet in August, to 56,000 feet in January, and the corresponding means, 87,500 feet from the longer durations, and 70,000 feet from the mean durations respectively.

(4.) That by April, 1884, a considerable portion of the larger reflecting particles had sifted out by gravitation, causing a minimum duration and brilliancy of the secondary glow; that, as this occurred coincidentally with a maximum development of the corona, or Bishop's Ring, we are led to conclude that a large portion of the finer material remained in suspension at nearly the same height as at first, and that, having become more homogeneous than at first, it was rendered capable of exerting its maximum diffractive power.

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* 1st and 2nd 'Warner Prize Essays.'

(5.) That while the present series of glows, both primary and secondary, reached a decided minimum everywhere about April, 1884, they subsequently exhibited a partial renewal of their former brilliancy and duration in the autumn and winter months of 1884 and 1885, similar to what is found to occur normally at such seasons through the influence of certain meteorological factors in the ordinary twilights—a fact which renders it impossible to arrive at any certain deductions regarding the rate of descent of the stratum as a whole.

(6.) That the brilliancy and duration of the phenomena were closely connected, but how far the duration was dependent on, or independent of, the precise quality or brilliancy of the glow does not exactly appear; of the two glows, the secondary seems to have far exceeded the primary in the amplitude of its variations, and its sensitiveness to general meteorological influences.

(7.) That the rapid decline of the glows both in brilliancy and in duration in the spring of 1884, and their subsequent re-appearances in the latter parts of 1884 and 1885, at a much reduced brilliancy, show that, while they were caused by the presence of an unusual quantity of dust in the upper regions of the atmosphere, this material gradually became eliminated, until, by the commencement of 1886, things had returned to their normal condition.

(8.) That while the duration of twilight was sensibly lengthened, during the prevalence of the glows, the action of the glow-causing material, except in as far as it tended to transmit the blue rather than the red end of the spectrum (partly by diffraction and partly by absorption), and thus produce certain unusual tints and sequences of colour, affected the sun's light in a manner somewhat similar to that produced by the dust and vapour particles ordinarily present in the atmosphere at lower elevations. That the final effects were produced by the prolonged reflection from the lofty stratum of rays (1) partly deprived of their red components by the action of the stratum itself, and (2) to a much larger extent subsequently deprived of their blue components by the ordinary dust and vapour particles of the lower atmosphere. It was, therefore, mainly an intensification of ordinary twilight phenomena, consequent on the presence, at a lofty altitude, of solid particles not usually existent there.

(9.) That similar unusually brilliant and long twilight glows, including the *secondary coloured* glow, which is one of the principal characteristics by which the present series has been distinguishable from ordinary twilight phenomena, have been witnessed at intervals in former years, and generally in association with volcanic phenomena.

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PART IV., SECTION V.

PREVIOUS ANALOGOUS GLOW PHENOMENA, AND CORRESPONDING ERUPTIONS.*

By the Hon. ROLLO RUSSELL.

List of principal ascertained volcanic eruptions from 1500 to 1886.		List of unusual atmospheric phenomena, such as blue suns, dry fogs, and red twilights, and general remarks.
Trölladyngia, Iceland	1510	
Hecla, Iceland	1510	
Etna	1535–37	
Vesuvius	1538	
Pichincha	1539	
Pichincha	1553	In the summer of 1553 there was a remarkable purple after-glow in Denmark, Sweden, and Norway. (See 'Science Gossip,' January 1, 1885, quoting from the Danish historian, Birkerod.)
Hecla	1554	
		In 1557 a dry fog is said to have prevailed extensively. ('Dewdrop and Mist,' Tomlinson.)
Teneriffe	1558	
Pacaya, Guatemala	1565	In 1576, the year of Titian's death, the sky is said to have been unusually red at Venice.
Pichincha	1577	
Kötlugia, Iceland	1580	
Volcan de Fuego, Guatemala	1581	
Reykianes, Iceland	1583	
Thringvalla Hraun, Iceland	1587	
Pichincha	1587	
Hecla	**1597†**	

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* The dates of eruptions are taken chiefly from the following works :—'The Earthquake Catalogue' (Mallet); Daubeny's 'Volcanoes;' Haydn's 'Dictionary of Dates;' The 'Encyclopædia Britannica;' Rees' 'Encyclopædia;' 'The British Almanack;' Raffles' 'Account of Java;' Sir W. Hamilton's 'Account of Vesuvius;' Murray's 'Guide to Southern Italy, 1868;' various works on Iceland and the Andes; the 'Philosophical Magazine;' Howard's 'Climate of London;' Judd's 'Volcanoes;' Wallace's 'Australasia;' 'Philosophical Transactions of the Royal Society;' and Captain Burton's "Volcanoes of Iceland," 'Proc. Roy. Soc. of Edin.,' 1875–6; 'Smithsonian Report,' 1885, Part I.

† This type, wherever used throughout this Section, indicates that the eruption is recorded as having been of a violent character.

List of principal ascertained volcanic eruptions from 1500 to 1886.	List of unusual atmospheric phenomena, such as blue suns, dry fogs, and red twilights, and general remarks.
Ternate, South Seas 1608	
Gunong Api, Banda, Moluccas 1615	
Hecla 1619	
Kötlugia, Iceland September 2 to 14, 1625	Ashes carried as far as Bergen, Norway.
Caraballos, Luzon 1627	
Vesuvius **1631**	Abbate Braccini measured the height of the ash cloud and found it to be 30 miles.
Ternate 1635	
Hecla From May 18 to Winter, **1636**	A glow was seen in the sky in Scandinavia in 1636, and the sailors arriving reported that for weeks the sky had seemed on fire after sunset. ('Science Gossip,' January 1, 1885.) Ashes were carried S.E. ('Smithsonian Report,' 1885).
Timor 1637–38	
Taal, Luzon 1641	
Palma, Canary Islands 1646	
Makian, Molucca Isles 1646	
Pacaya, Guatemala 1651	
Ternate 1653	
Sinchulagu 1660	
Kötlugia, Iceland November 3 to 12, 1660	In January, 1661, in Denmark the sky seemed a bath of lurid fire. ('Science Gossip,' January 1, 1885, from Birkerod, Danish historian.)
Pacaya 1664	In 1665 a red twilight is mentioned as having been seen in London. "At this fatal season the sunsets were unusually splendid. . . Long after the sun had set, the sky was stained with crimson." (Harrison Ainsworth's 'Old St. Paul's,' Book III. chap. iv.)
Omato, Andes 1667	
Pacaya 1668	
Etna 1669	
Pacaya 1671	
Ternate 1673	
Amboyna 1674	
Palma, Canary Isles 1677	
Celebes **1680**	
Krakatoa April or May 1680 (See 'Verbeek's Krakatau,' also *ante*, page 10.)	According to Birkerod, the same kind of appearance as in 1661 was again seen throughout Denmark on May 22, 1680, at sunrise. Long before the sun rose the entire heavens were filled with a blood-red light. The people were terribly alarmed, as in 1661. ('Science Gossip,' January 1, 1885.)
Etna 1682	
Gunong Api 1690–91	

List of principal ascertained volcanic eruptions from 1500 to 1886.	List of unusual atmospheric phenomena, such as blue suns, dry fogs, and red twilights, and general remarks.
Hecla .. February 13 till August, **1693**	Ashes fell in Norway and Scotland.
Sorea, South Seas 1693	
Vesuvius 1694	
Celebes **1694**	
Amboyna **1694**	
Gunong Api.. .. November 20, **1694** to April, 1695	
Vesuvius 1696	
Carguairazo, Chili .. .. July 19, 1698	
Vesuvius .. .. .. May, 1698	
Palma, Canary Isles 1706	
Vesuvius .. May 20 to August, **1707**	
Japanese Volcano **1707**	
Santorin May 25, especially July 25, **1707**	
Siao, near Celebes 1712	
Taal, Luzon 1716	
Hofs Jökul, Iceland 1716	
Eyafialla Jökul, Iceland 1717	
Vesuvius .. .. April to June, 1717	Intense darkness at 100 miles from the volcano.
Kötlugia, Iceland May 11 till Autumn, **1721**	Atmospheric phenomena [glows ?] were seen from Persia to France in 1721. (Kiessling's Essay in 'The History and Work of the Warner Observatory,' 1721, was remarkable for a dry fog of much intensity in Germany. (Kaemtz's 'Meteorology.') Strange appearances of the sun were seen in Persia in 1721. ('Nature,' Col. Kincaid, April 24, 1884). In 1721 the sun for two months was seen red, through a lofty haze. (Richard's 'Histoire Naturelle de l'Air.')
Hithoel, Iceland 1725	
Krabla, Iceland .. 1724–25–27–29–30	
Irasu, Central America .. 1723–26	
Öroefa Jökul, Iceland 1727	
Hecla 1728	
Hrossadels Hraun, Iceland 1728	
Antisana 1728	
Leirhrukr .. From January 30, 1729	
Vesuvius 1730	
Lancerote, Canary Isles 1730	
Etna 1732	In 1733 a dry fog is said to have prevailed extensively. ('Dewdrop and Mist,' Tomlinson.)
Etna 1735	
Kamschatka Mountain 1737	
Awatschinskaja, Kamschatka .. 1737	
Vesuvius .. .. .. May 20, 1737	

List of principal ascertained volcanic eruptions from 1500 to 1886.	List of unusual atmospheric phenomena, such as blue suns, dry fogs, and red twilights, and general remarks.
Tubatchinski, Kamschatka 1739	
Sangay, 1° 45′ S. (16,080 ft.) .. 1742	
Cotopaxi, Ecuador May and November, **1744**	
Sandfells Jökull, Iceland 1748–49–50–51–52	
Vesuvius October 19 to November 9, 1751	
Skeidarar Jökull, Iceland 1753	
Vesuvius .. .. December 2, 1754	
Hecla .. .. .. November 19, 1754	
Kötlugia, Iceland .. October 17, **1755** continued violent November 1, and did not cease till August, 1756	On October 23 or 24, 1755, a shower of dust fell on a ship about 75 miles north-west of the Shetland Isles.
Etna .. .. March, 1755	Igneous meteors, halos round sun and moon, &c., were seen all over Europe some time before the Lisbon earthquake of November 1, 1755. ('Earthquake Catalogue.')
	In a letter from M. Saccheti, of Lisbon, he states that on October 30, the day before the Lisbon earthquake, the atmosphere and light of the sun had a cloudy appearance and notable obfuscation. ('Phil. Trans.,' 1755, p. 410.)
	M. Bertrand is quoted as saying that there were fogs, and the sun looked larger than usual after the Lisbon earthquake. ('Observations en Physique,' 1783, p. 201.)
	In western Europe there was a peculiar mist some days before the Lisbon earthquake. ('Dewdrop and Mist,' Tomlinson.)
	On November 1, 1755, in the morning, in Cornwall, the sky was very full of little fiery-red clouds, in the afternoon very lowering, and in many places of a very odd copper colour. The atmosphere was excessively thick and dark. ('Phil. Trans.' 1755, p. 510.)
	At Dublin, on December 18th, 1755, at 4 p.m., there was a red light like fire. ('Phil. Trans.,' 1755, p. 795.)
	On December 27, 1755, at Rocroy, France, and other places, the heavens appeared as if all on fire. Igneous meteors were common in Switzerland for some time after the earthquake. At Maestricht, clouds and auroræ were often observed about February 20, 1756. ('Earthquake Catalogue.')
	On January 1, 1756, in the west of Ireland, from 4 to 7·18 p.m., the sky appeared like a sea of flame, the last 18 minutes being most brilliant.
Luzon .. .. .. December 26, 1756	
Vesuvius .. April 24, 25, 26, 27, 1756	

List of principal ascertained volcanic eruptions from 1500 to 1886.	List of unusual atmospheric phenomena, such as blue suns, dry fogs, and red twilights, and general remarks.
Vesuvius .. .. .. January, 1758	
Etna .. .. April 18 and May, 1759	
Jorullo, Mexico .. September 28, 1759	
Vesuvius .. .. November, 1759 and December 24, 1760	Lambert made his observations on the twilight on November 18, 1759, and found the culmen crepusculi to be 3° 15′ above the horizon 1 hour 38 minutes after sunset at Augsburg.)
Peteroa, Chile .. December 3, 1760	
Peteroa 1762	
Etna .. .. .. February, 1763	
Moluccas .. .. September 1, 1763	
Hecla .. April 15 to September 7, **1766**	
Albay or Mayon, Luzon **1766**	
Etna 1766	
Vesuvius .. .. .. March, 1766	
Vesuvius .. August and October, 1767	
Cotopaxi .. .. .. April, 1768	
Colima 1770	
Hecla 1772	
Papandayang, Java **1772**	
Vulcano .. .. February 14, 1775	
Pacaya, Guatemala .. .. July, 1775	"*Asama.* The most frightful eruption on record. Rocks from 40 to 80 feet in some of their dimensions were hurled through the air in all directions. Towns and villages were buried. One stone is said to have measured 264 feet by 120 feet; it fell into a river and looked like an island. Records of this eruption are still to be seen in the form of enormous blocks of stone scattered over the Oiwake plain, and in a lava stream 39 miles long." (Prof. Milne in 'Brit. Assoc. Rep.,' 1887.)
Vesuvius .. .. March 28, 1776	
Etna .. .. .. April 27, 1776	
Vesuvius **1779**	
Etna and Vulcano 1780	
Etna .. .. April 24 and all May, 1781	
Asama, Japan **1783**	*a.* The year 1783 was remarkable for a thick dry mist or fog which spread over Europe in June, and continued, more or less, for three or four months. Kaemtz says that the dry fog presented the following phenomena: In some places objects at 5 kilometres (3 miles) distance could not be distinguished; the sun was red and was invisible some time after rising, and before setting. The fog reached Copenhagen on May 29; La Rochelle on June 6 and 7; Dijon on June 14; Franeker, Netherlands on June 19; Spydberg, Norway, on June 22; St. Gothard and Buda on June 23; Stockholm on June 24; Moscow on June 25; Syria at the end of June; the Altai on July 1. (Kaemtz's 'Meteorology.') *b.* "The fog of 1783 commenced about the same day (June 18) at places distant from each other, such as
Reykianes, Iceland .. .. May, 1783	
Skaptar Jökull, Iceland, end of May, June, most violent June 8 and 18, **1783**	

List of principal ascertained volcanic eruptions from 1500 to 1886.	List of unusual atmospheric phenomena, such as blue suns, dry fogs, and red twilights, and general remarks.
1783.	Paris, Avignon, Turin, and Padua. It extended from the N. coast of Africa to Sweden. It lasted more than a month. The lower air did not seem to be its vehicle, for, in some parts, the fog came with a S., in others with a N., wind. Abundant rains and the strongest winds did not dissipate it. In Languedoc, its density was such that the sun was not visible in the morning up to 17° altitude above the horizon; the rest of the day the sun was red, and could be observed with the unprotected eye. At Geneva the humidity during its prevalence was as low as 68°, 67°, 65°, and even 57°. At the time of new moon, the nights were so bright that the light was compared to that of a full moon, even at midnight." (Arago, 'Annuaire pour l'An 1832.') *c.* A few days before the 24th of June, 1783, a peculiar fog spread itself over Holland. On this day it became denser, and continued for a long time thereafter, but its thickness varied from day to day. At first a sulphurous smell was very evident. A list is given of a large number of plants which appeared to be damaged by the blighting influence of the fog. On the North Sea, according to reports of captains, nothing was noticed till June 21, and after this date the mist was so thick as to hide everything from view. In Holland, the disc of the sun could be gazed at with the naked eye. (Brugmans' 'Verhandeling over een Zwavelagtigen Nevel,' 1783.) *d.* On May 29, 1783, a peculiar fog appeared at Copenhagen, and lasted until the end of September. The sun's disc was altogether obscured at rising and setting, and half obscured during the daytime. The sky was blood-red at rising and setting of the sun. Great consternation prevailed in northern Europe. ('Nature,' December 10, 1885.) *e.* On the 18th of June, 1783, the whole of France, Piedmont, and other parts of the continent of Europe were affected by a thick sulphurous mist. It extended to Asia, Africa, and North America. This haze had, in some places, a peculiar smell, and was unpleasant to the eyes. The sun was invisible when near rising or setting, and red and rayless, or bluish-white and rayless, during a large part of the daytime. ('Phil. Mag.,' vols. iii. to v.) *f.* In England, the fog or haze with the above-mentioned characteristics began on June 16. It lasted about two

List of principal ascertained volcanic eruptions from 1500 to 1886.	List of unusual atmospheric phenomena, such as blue suns, dry fogs, and red twilights, and general remarks.
1783.	months, and no variety of weather dispersed it. (White's 'Selborne,' &c.) *g.* "It did not clear till Michaelmas." ('Phil. Trans.,' vol. lxxiv., p. 285.) *h.* Cowper alludes to "beacons in the skies" and "Fires from beneath, and meteors from above— Portentous, unexampled, unexplained." ('The Task,' Book II.) *i.* De Saussure speaks of the constant dry haze of unusual density seen in the Alps in the end of June and in July, 1783. The monks of St. Bernard declared to him that it was not haze but smoke. ('Voyage dans les Alpes.' 8vo. edition, vol. vi., p. 362, &c.). *j.* There are many allusions in the literature of the time to the strangely persistent character of the haze and the appearance of the sun. (See especially 'Observtions en Physique' for 1783, p. 201, and for 1784.) *k.* The following observations are taken from the 'Ephemerides Societatis Meteorologicæ Palatinæ,' 1783:— At Mannheim the dry haze began on June 16 and ended on October 6, but there were occurrences of the same kind of mist, occasionally, after this date. The sun was red, like molten iron. On the days when the mist was densest, stars were not seen below 40° altitude. At Berlin the fog and red sun lasted from June 17 to 29. At Buda (47° 30′ N. 19° 2′ E.) the fog began on June 23. At Peissenberg the fog began on June 17. On July 9 it was "dense as an Egyptian plague." At Sagan (51° 37′ N. 15° 19′ E.) it began on June 17 and continued in September, October, and November. At Prague the fog began on June 16, and on the 18th the sun sank of the colour of blood. On the 19th the fog was thick and the sun pale. On the 18th, at night, the only stars visible were surrounded with halos. On the 24th little clouds towards north and west were coloured red at sunset. The stars had halos. On the 25th there were very long clouds, like haze, from the west to N.N.E. On the 28th the sun, when seen, was pale, and on the 29th and other days could be gazed on with the naked eye, and looked like an eclipsed moon. On July 8 to 11 the moon was red, on the 8th the sun was

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1783.	red, and on the 10th was not seen in setting. On September 1 the fog was thick and the sun pale; on September 23 there were red clouds at sunset and a double iris. At Geneva the dry fog began on June 17, but from May 28 to July 5 the sky was intensely misty, and was continuously misty till August 7. The mist was always blue or verging to blue, sometimes it was reddish, but never grey. It was higher than the tops of the Alps. No change of wind dispersed it. The sun was red. At Göttingen the sun was noted as red at 7 p.m. on June 18, and on the 19th the mist began, which for a long time caused the sun and moon to appear red. At Düsseldorf the fog began on June 16. At Würzburg (49° 47′ N. 9° 56′ E.) on June 16. At Erfurt on June 17. At Mount St. Andex, in Bavaria, and at Tegernsee, on June 18. At Munich on June 17. At Rupel (51° 7′ N. 47° 17′ E.) the fog began on June 18, and the sun was red for a long time. At Middelburg (51° 29′ N. 3° 37′ E.) the mist began on June 19. At Stockholm the fog began on June 24. At Franeker (53° 12′ N. 5° 31′ E.) the mist began on June 19; the wind was S.W. on the 18th and 19th, chiefly N.W. from the 20th. The mist penetrated into houses, and its sulphurous character caused to some persons inconvenience in breathing. At Neuchatel an east wind increased the fog, a west wind, if very strong, dispersed it, but it returned immediately on its cessation. The fog began on June 17, and the sun could be gazed at at any time of day. At Dijon there was a slight haze in the sky on June 14. This was denser on the 18th, much denser on the 22nd. The sun was obscured and deprived of rays, pale red, and like the moon, with distinct disc. In setting and rising it was red. At Rome, on June 4, there was a coloured circle round the moon. On the 16th and following days, fog and dry haze. On June 18 a lofty mist; moon reddish. The sun's light was weak on the 18th and 19th. The clouds came from W.S.W. on the 18th, and S.W. on the 19th and 22nd. On the 25th the sun was pale, and red

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	1783.	in setting. On the 24th the moon was blood-red in rising. These phenomena continued to the middle of July. On July 25 the clouds were as if on fire after sunset. At Pavia the sun was red or ruddy, and rayless, and easily looked at. The mist was like smoke or dust. The moon was red. The sky was white and veiled on the afternoon of June 18. Afterwards the mist was so thick that large houses two miles off could hardly be seen. At Florence the fog began early in June. At Moscow the air was misty during July. In Syria there was a thick fog from the end of June, the sun was blood colour, but rarely seen. ('Ephemerides Societatis Meterologicæ Palatinæ,' 1783.)
Hecla	1784–85	
Vesuvius	**1785**	
Vesuvius	1787	
Etna	1787	
Kilauea, Sandwich Islands	1789	
Vesuvius	1790	
Etna	May 11, 1792, to 1793	
Illigigama and Kiusiu, Japan	April 1, 1793	
Alaid, Kamschatka (12,000 feet)	1793	
Vesuvius	**1794**	
Colima	1795	
Klutschewskaja-Sopka, Kamschatka	1795	
Mount Edgecumbe (57° N.)	1796	
Chahorra, Teneriffe	1798	
Izalco	1798	
Volcan de Fuego, Guatemala	1799	Humboldt, at Cumaña, observed a reddish vapour in the sky from October 10 to November 3, 1799. It covered the sky for some minutes each evening, and caused it to assume the colour of fire. On November 4 there was a great earthquake, then a magnificent sunset upon an indigo blue sky, lined with golden clouds and illuminated by prismatic rays of colour.
Cotopaxi	1803	
Vesuvius	August 11, 1805	
Merapi, Java	1807	
Izalco	1805–07	
St. George, Azores	May 1, 1808	On May 6, 1808, the twilight at Plaistow, at 9 p.m., was brilliant in the highest degree. (Howard's 'Climate of London.')

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Etna .. .. .. March 26, 1809	On April 1 and 2, 1809, there was an extensive blush on the evening twilight, of rose-coloured red haze. On March 27 lunar halo and coloured cirrus. (Howard, Plaistow.)
Azores.. .. .. January 31, **1811**	On February 3rd, 1811, there were fine red-coloured cirri in an apparently calm region. On February 8 sky highly coloured at sunrise. (Howard, Plaistow.)
Azores.. .. .. June 11 to 16, 1811 Vesuvius .. .. October 12, 1811 Etna .. .. October 25 and 27, 1811 (Cinders carried great distance.)	There were finely-coloured skies from June 16 through July, August, September, October, November, and December, 1811. (Howard). Red twilights October 15 and 19, and on October 31 sun and moon appeared red on the horizon. (Howard, Plaistow.)
St. Vincent .. .. April 30, **1812** Vesuvius .. .. .. June 12, 1812	On May 8, 1812, the evening twilight was luminous and coloured, with a striking appearance. There was a high haze on the 19th and 26th, a fine sunset on the 28th. There were several red sunsets, &c., through June, from the middle to the end of September, and in the end of October, at Plaistow. (Howard.)
Vesuvius .. May to December, 1813 Vesuvius .. .. December 25, 1813 (Violent discharge of ashes.)	On May 31, 1813, there was a brilliant orange twilight. Also June 1, 2, 8, 12, 25, 27, July 12, 25, 27, 28, 29 (fine blush of red to two hours after sunset), 30; August 1, 2, 9, 20, 22, 24, 25, 26, 29. Also during September, particularly the 16th, on October 3 and 25, November 18, and December 31; on this last day much red in the morning and evening sky, and a peculiar smell of electricity. (Howard, Tottenham.) On September 21, 1813, the sun was pale at Forli. (Mallett's 'Earthquake Catalogue,' Brit. Ass. Rep.)
Kamschatka (submarine) 1814	
Albay, or Mayon, Luzon **1814**	On November 5, 1814, there was a streaked orange sky at sunset; on November 10, a brilliant twilight, lemon surmounted by purple; on November 12, orange, delicately varied with dusky horizontal striæ. On December 14, a red sunrise. On January 1, 1815, a rose-coloured sky at sunset. (Howard, Tottenham.)
Tomboro, Sumbawa* April 7 to 12, **1815**	On May 15, 1815, there was a luminous twilight, and on May 18 a red sunset. On June 29, a bright orange twilight, and purple glow above; on July 2, a luminous twilight, the clouds much coloured; on July 9, an orange twilight; on July 12 and 17, coloured twilights; on August 13, coloured cirri; on August 18, a brilliant

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* This eruption was the greatest since that of Skaptar Jökull in 1783. For three days there was darkness at a distance of 300 miles.

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1815.	sunset; on September 3, cirri remained red long after sunset; on September 4, a brilliant twilight; on September 13, it is noted that "the evening twilight has been generally coloured of late, and at times streaked with converging shadows, the origin of which could *not* be traced to clouds intercepting the light;" on September 17, most beautiful coloured sunset; on September 27, nimbi reflecting coloured light 30 minutes after sunset; on October 2, luminous twilight; on October 7, red sunset, orange below; on October 18 and 20, coloured sunrise; on October 21, finely-coloured cirri at sunset; on November 2, much redness in the twilight; on November 3, coloured sunset; on November 4, purple and orange after sunset. (Howard, Tottenham.) At Clapton, near London, the following notes, made in 1815, are of interest:—June 28, pale golden above sunset, greenish-blue to the north, a fine pink blush above; June 30, nearly the same; July 2, crimson cirri, &c. Tunbridge Wells, September 5, the sky exhibited in places a fire; 7th, fine deep red refraction at sunset and for some time after; 9th, at sunset fine red blush, with diverging red and blue bars; 14th, beautiful sunset. (Forster's Journal, 'Phil. Mag.') This year, 1815, is the most remarkable as regards sunset lights recorded up to this date.
Vesuvius .. .. 1818 Colima .. .. 1818 Hecla .. .. .. October 31, 1818 Goenoing, Batavia October 11 to 21, **1818** (See 'Phil. Mag.,' 1819.)	On July 4, 6, and 24, 1818, there were finely-coloured twilights, that on the 6th being very remarkable at 3 a.m.; and on the 24th the clouds were of a rich crimson-lake, and orange colour; on July 13, 14, 20, and 21, the sunsets were fine; on August 4 there was a double gradation of beautiful colours at sunrise and sunset; on August 7, extremely rich glowing colours; on August 9, a finely-coloured sunset, and frequently to the end of the month fine sunsets, diverging shadows, and appearance of dust; on October 2, magnificent blood-red tints, orange and flame-colour at sunrise; and on October 8, a great rosy arch at sunset; on September 25, halo and parhelia; on November 23, rosy cirri, orange twilight on November 25, solar halo; January 7, 1819, red cirri at sunrise. (Howard, Tottenham.) Edwin notes a red colour lasting more than half an hour after sunset on June 29, 1818, and similar appearances in July. (Edwin's MS. Journal, at R. Met. Soc.)
Etna .. .. .. April to June, 1819 Denodur, Bhooj .. June 20, 1819	

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Vesuvius .. .. January 16, 1820 Amboyna 1820	
Gunong Api, Banda, June 11 and 12, 1820 (A. M. Clerke, 'Times,' December 11, 1883.) Klutschewskaja-Sopka, Kamschatka, probably March, 1821 Bourbon .. .. February 27, 1821 On April 11 still much smoke. Irasu, Central America .. .. 1821 Eyafialla Jökull, Iceland December 19, 1821 very violent till February 28, 1822	On July 12 and 14, 1821, there was a very beautiful sunset. On August 18 a blue sun, seen in London, Sussex, Worcester, &c. There was a haze and the sun looked like quicksilver. (See Forster, 'Phil. Mag.,' vol. lviii., pp. 234 and 314; also Howard's 'Climate of London,' vol. iii., p. 58.) At 9.20 on August 18 the blue sun was observed by a great number of persons in the streets. It lasted about half an hour. The atmosphere on the following days was hazy. (Edwin's 'Journal.') At Paris, on August 18, the sun at 5 p.m. was enfeebled by dense vapours, and absolutely white. ('Annales de Chimie,' tome xviii., p. 420.)
Gunong Ber Api, Sumatra .. July 22, 1822 Vesuvius .. .. February 13, 1822 Vesuvius .. .. .. July 10, 1822 Vesuvius, October 22 till November 4, 1822 Galung, Java .. October 8 to 12, 1822 Merapi, Java .. .. December 29, 1822 Kötlugia, Iceland .. .. July 26, 1823	There appear to be no detailed records of exceptional sky phenomena in 1822; but Forster mentions a fine sunset, gold and deep red, on November 2, and a very green sky and red clouds on November 22 at 7.10 a.m. On Jan. 8, 1823, there were red clouds at sunrise. ('Trans. Roy. Soc. Edin.,' 1839, p. 390.) From March to September, 1823, the sunset skies near London were very bright, and the clouds frequently red. On Sept. 24 the whole sky was tinged a lively red colour, remarkably bright in north-west. (Edwin's 'Journal.') With regard to the eruption of Vesuvius on October 22, Sir William Gell wrote as follows on October 23:—"When it (a magnificent column of smoke, stones, and fire) reached an enormous elevation, about 20,000 feet, the whole turned into the most beautiful silver clouds, and, after continuing to spread for about an hour, filled the whole atmosphere, and quite put an end to the sun, which has appeared no more, except as a *sky-blue* spot in the dark clouds of to-day." ('Journal and Correspondence of Miss Berry,' vol. iii., p. 325.) Bishop Heber in his journals describes the sunset of September 18, 1823, as unprecedentedly gorgeous.
Lancerote, Canaries July 31 to October or November, 1824 Reykianes, Iceland .. .. .. 1824 Amboyna .. .. 1824 Tolima, Chili .. .. .. 1826 Perace, Columbia .. .. .. 1827 Japanese Volcano .. .. May 26, 1828 Atitlan .. .. 1828 Etna .. .. .. April 16, 1830	Early in August, 1824, there was a peculiar mist round the sun in Tuscany. ('Earthquake Catalogue.')

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Graham's Island or Ferdinandéa, or Siarra, or Julie, or Nerita,* July 10 to early in August, **1831** Etna .. .. .. February 17 1831 Vesuvius .. .. .. summer, 1831 (Crater cleared of a mass of scoriæ.) Barbadoes .. early in August, 1831 Babujan Islands .. .. .. **1831** (Great eruption.) Pichincha .. .. **1831** (In full activity.)	In 1831 a number of remarkable atmospheric effects were seen, similar to those of 1883. Marshall noted as follows respecting June, 1831, at Kendal :—" The evenings have frequently been attended by a remarkably red sky, but this appearance has not often been succeeded by fine days, which is mostly the case." (Brewster's 'Journal of Science,' vol. vi. 1832.) In Edwin's 'Journal' we find the following remarks :—June 21, 1831, a fibrous sky, tinged lively red and yellow at sunset. On June 1 and 6 a brilliant twilight; June 13, brilliant twilight; June 15, cirri, resembling folds of a curtain, tinged deep red in the east at 8; June 26, clouds tinged brilliant red and orange by setting sun; on July 21, cirri tinged deep fiery red, and of a very stormy character; July 25, a fine sunset, Venus a beautiful object through the haze in the west; August 13, a warm glow on the east horizon; August 19, clouds tinged dull red, brilliant twilight and very transparent atmosphere; September 24, luminous twilight. (Edwin's 'Journal;' see also 'Phil. Trans.,' 1832.) Father Denza, of Moncalieri Observatory, mentions the grand sunsets seen throughout southern Europe in September, 1831. The sky at sunrise and sunset was deep orange and red. ('Daily News,' December 14 or 15, 1883.) According to Kaemtz, a very prolonged twilight was noted from Madrid to Odessa in September, 1831. It was most remarkable on September 24, 25, and 26, when it continued till 8 p.m. On the 24th, at Halle, the sky was not of a deep blue, though it was clear, and the sun had the dead brilliancy of the moon. These appearances were seen on the coast of Africa (haze and blue sun) on August 3; at the Bermudas, August 11 and 12; (blue sun) at Odessa, August 9; in southern France, August 10; at Mobile, U.S., August 13, 14, and 15; (blue and green sun) at New York, August 15; (blue sun) Canton, end of August.

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* The submarine activity which produced the volcano called Graham's Island was made the subject of several good observations. On July 10 and 11 the fiery column was magnificent. In the beginning of August there was an immense column of dust; on August 5 the dust was carried to a distance by the wind. Professor HOFFMANN, observing from Mount St. Galogero, and Dr. SCHULTZ, from near Palermo, at 14 geographical miles distant, found the height of the smoke column to be at least 20 kilometres, that is about 13 miles, on the 31st of July. The position of the island was 37° N. 12° E.

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1831.	At Washington in October, especially October 12, when a red light lasted long after sunset; on October 13 the midday sun was silvery and ghastly; between 3 and 4 p.m. it was greenish-blue. (Niles' 'Register;' see 'Nature,' May 8, 1884.) In Belville's MS. 'Journal,' where remarks are very rare, a lurid sky is noted on August 5 at Greenwich. In August, 1831, there was an unusual brightness in the west after sunset in Europe; and in many places the sun was dim and violet. At Canajoharie, U.S., on August 4, the sun at 5 p.m. was dim and violet. At Albany, from August 12 to 31, the western sky was deep red after sunset. One afternoon the sun was pale, like the moon, and slightly green. ('New York Meteorology,' 1826–50, p. 14.) Professor Palmieri, of Naples, is reported to have said that in 1831, "at the time of the eruption of Sciacca, the atmosphere permitted of such a diffusion of the light from the volcanic fire, that at Campobasso, in the heart of Calabria, people could read by the intense light, and the day was lengthened by about two hours." ('Daily News,' December 8, 1883.) From the 2nd to the 4th of August, 1831, optical effects were seen, simultaneously at Madrid, Genoa, Rome, Berlin, Odessa, Irkutsk, and Werchneudinsk. (Kiessling's 'Die Bewegung des Krakatau-Rauches.') The extraordinary dry fog of 1831 was observed in the four quarters of the world. It was remarked on the coast of Africa on August 3, at Odessa on August 9, in the south of France and at Paris on August 10, in the United States on August 15, &c. The light of the sun was so much diminished that it was possible to observe its disc all day with the unprotected eye. On the coast of Africa the sun became visible only after passing an altitude of 15° or 20°. M. Rozet, in Algeria, and others in Annapolis, U.S., and in the south of France, saw the solar disc of an azure, greenish, or emerald colour. The sky was never dark at night, and at midnight, even in August, small print could be read in Siberia, at Berlin, Genoa, &c. On August 3, at Berlin, the sun must have been 19° below the horizon when small print was legible at midnight. (Arago, 'Annuaire, pour l'An 1832.') On August 10, 1831, at St. Severs, the sun at 5 p.m.

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1831.	was like the moon; an hour after, it had a dull blue colour. The horizon at sunset was of a vivid hue as it appears on hot days. A filmy cloud uniformly spread over the sky seemed to be the cause of the phenomenon. The same appearances were seen in the south of France and in North Italy. (Kiessling, 'Pogg. Ann.,' xxiii., p. 443.) On September 24, 25, and 26, 1831, most remarkable sunsets were generally noticed at Liepsic and Plauen, in Germany. The redness of the sky lasted one hour and a half after sunset. ('Met. Zeitschrift,' January, 1886.) The eruption at Barbadoes was followed by great obscurity and a prevalence of a blue sun at the Bermudas on August 11, the strange colour lasting the whole day. 'Brit. Association, 10th Report,' p. 10.) "I was then (August, 1831) surveying the horse-shoe reef of Anegada (W. Indies). . . The whole sky was decidedly overcast, but of a decided bluish colour." Wind fresh, E.N.E. Whitish objects appeared light blue in the W. Indies. (Schomburgk's 'History of Barbadoes.') There was an extraordinary light on the north horizon at Fahlun, Sweden, on November 17, 1831. ('Earthquake Catalogue.')
Atitlan 1833	
Vesuvius .. .. .. August, 1834	In June, 1834, after-glow in Switzerland. (Necker, 'Biblioth. Univ.,' tome xxiii., p. 374.)
Merapi, Java 1834	
Coseguina Osorno Aconcagua } .. January 20, **1835**	Bright sunset skies in England in February. (Edwin's 'Journal.')
Osorno and Corcovado, November 11, 1835	
Gounung Api, Banda 1835	
All the volcanoes of Chili, February 20, 1835	
Guadaloupe 1836	
Awatska (8,900 feet) **1837**	There are several notices of after-glows in 1837, especially in October, when they lasted 1 hour 36 minutes. (Necker, 'Biblioth. Univ.,' tome xxiii., p. 374.) On August 21, 1837, there was a red sky at Lasaya, Tasmania, and terrible explosions. (Earthquake Catalogue.)
Kilauea .. .. .. June, 1840	
Mount Reignier, 46° N. .. 1841, 1843	

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Merapi, Java .. .. 1845 Antuco, South America .. .. 1845 (Somerville's 'Phys. Geog.,' 5th ed., p. 122.) Hecla .. .. from September 2, **1845**	At Makerstoun, Scotland, on September 2, 1845, at 6 a.m. there was cirrous haze to the west, tinged with red. On September 8, at 5 a.m., the sky was red in the east; at 6 a.m., very red in the east; from 11 to 12 there was a solar halo; at noon a thick cirrous haze. ('Makerstoun Mag. and Met. Obs.,' pp. 845–6, pp. 227–9.) On September 2 ashes covered a ship near the Orkney Islands, more than 500 miles from Hecla. On September 8, 1845, at Greenwich, there were linear cirri in the north-west at 4 p.m. At 6 p.m. "the sun, which is shining through a dense haze, has the appearance of a bright vermilion ball." At 8 p.m. "a few small clouds in the north-west, but horizon hazy all round; about sunset there were several long lines of cirri in various directions, which were coloured with a most beautiful red tint by the setting sun." Haze till September 10. On October 3, most peculiarly coloured clouds soon after 6 p.m. (Greenwich Magnetical and Meteorological Observations, 1845.) Near London, on September 6, 1845, at 6 p.m., there was a brilliant orange-coloured sky and a brilliant and clear sunset; the sun's disc, silvery-white, just touching the horizon. A few gold-coloured clouds around and above it, forming a very beautiful sky. The solar rays visible at 10 a.m. downwards and upwards. On September 7, very transparent atmosphere, and sky lovely blue. Very clear horizon all round, except low bank of haze. Very clear sunset at 6.30, gold colour in south-west. Splendid orange and red sunset on October 3; a yellow sky and haze on October 11; and a bright sky on other days during the month. (Edwin's 'Journal.')
Amugura, Fiji .. .. .. **1846** Zugar Islands, Red Sea .. .. 1846 Hecla .. .. .. April 15, **1846** On April 15, there were "three new craters, projecting pillars of fire to the height of 14,000 feet." (British Almanack, 1847; Haydn's 'Dictionary of Dates;' and Woodward and Gates 'Encyclopædia of Chronology.')	From the middle of April to the end of May (May 31), 1846, there was an extraordinary after-glow in Switzerland. It lasted 1 hour 30 minutes on May 21, 1 hour 20 minutes on May 23, 1 hour 25 minutes on May 28, about 45 minutes on May 31. It had the appearance of a column or pillar of red light, and was at one place attributed to a supposed conflagration. ('Phil. Mag.,' 1846, vol. xxix., p. 177.)

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Irasu, Central America 1847	
Vesuvius .. .. February, 1850	
Gunong Api, Moluccas 1852	
Volcan de Fuego, Guatemala .. 1852	
Etna .. .. .. August, 20, 1852	
Schiwelatch, Kamschatka February, 1854	
Vesuvius .. .. May 1 to 28, 1855	Cone of pink light lasting 55 minutes after sunset, November 23, 1855. In December, 30 minutes after sunset. (Maskelyne, 'Nature,' January 24, 1884.)
Cotopaxi 1855	
Sanguir, Philippine Islands March 2, 1856	On November 11 and 12, 1856, after-glow and cone of pink light for nearly an hour after sunset; on December 15, 18, and 19, for 40 minutes; on January 15, 16, 19, 26, February 8, 1857, from 45 minutes to 1 hour. (Maskelyne, 'Nature,' January 24, 1884.) On December 13, 1856, at 30 miles from Cotopaxi, during a fall of ashes, a purple sky was noted. ('Nature,' March 27, 1884.)
Japanese volcano .. September, 1856	
Cotopaxi .. .. December 13, 1856	
Vesuvius .. .. May and June, 1858	
Kötlugia .. .. May 8 to 27, 1860	
Vesuvius .. .. December 8, 1861	
Vesuvius 1862	Unusual colours of sunsets during and after the eruption. (Col. Stuart Wortley, 'Times,' December 14, 1883.)
Makian, Molucca Island, December 29, 1862	
Island in Mediterranean August 12, 1863	Fine sunsets noted (von Bezold, in 'Zeit. f. Met.').
Merapi, Java 1863, 1864	
Etna .. .. February to July, 1865	
Santorin .. .. February, 1866	
Vesuvius, November, 1867, to March, 1868	
Icelandic Volcano* 1867	
Japanese volcano .. .. March, 1867	
Vesuvius, October 8 and November 19, 20, 1868	
Etna .. .. .. November 28, 1868	Red sunsets in December, 1868 (R. Russell's 'Register,' MS.). On December 16, 1868, there was a gorgeous deep red sunset at Richmond, Surrey; on December 18, a peculiar white sunset; on December 20, a red sunset; and on December 23 and 30, a fine sunset.
Izalco, San Salvador May 19, 1869	
Icelandic Volcano* 1869	
Etna .. .. May 26 to June 7, 1869	
Colima .. .. June, 1869	Red sunsets seen at Richmond, Surrey, July 13 and 16, 1869; on August 9 a pink light at sunset; on August 12,

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* "The Volcanic Eruptions in Iceland in 1874 and 1875." By Captain BURTON. 'Proc. Roy. Soc. Edinburgh,' 1875–76.

List of principal ascertained volcanic eruptions from 1500 to 1886.	List of unusual atmospheric phenomena, such as blue suns, dry fogs, and red twilights, and general remarks.
	14, 21, and 22, red sunsets; on September 27, dark red clouds. (R. Russell's 'Register,' MS.) Evening *Alpenglüh* very fine on August 23, and morning glow on August 24, 1869. (Tyndall's 'Fragments of Science,' p. 124.)
Izalco, San Salvador February 23, 1870	
Icelandic Volcano* 1870	
Vesuvius .. April 23 to May 3, **1872** (Ashes discharged April 29.)	On May 6, 1872, sand fell all over Italy, the sun looked pale, and the sky was hazy. ('Comptes Rendus,' vol. lxxiv., p. 1,268.) Pumice to the depth of several feet fell at Pompeii after the eruption. ('Daily News,' December 2, 1886.)
Japanese volcano .. .. June, 1872	
All the volcanoes of the New Hebrides, 1872	
Merapi, Java .. .. .. April, **1872**	At Madrid, red sunsets similar to those of 1883 were seen in 1872. (The 'Times,' December 4, 1883, Madrid Correspondent.)
Skaptar Jökull .. January 9, 1873	
Icelandic volcano About December 25, 1874	
Etna .. .. .. August 29, 1874	
Vatna Jökull March 29 and during April, **1875**	The air in central England was very misty in the beginning and middle of April, 1875. On the top of Snowdon, on April 15, the haze seemed to extend to a great height above the tops of the mountains, and the horizon was hazy all round. (Hon. R. Russell's 'Notes.') On August 9, 1875, M. Cornu, and on September 22, 1875, M. Touchimbert, saw an arc of light in the west a little after sunset. ('Bulletin Internationale de l'Observatoire,' and 'Comptes Rendus,' 1875, vol. lxxxi., p. 600.)
Mauna Loa, Sandwich Islands .. 1877	
Krakatoa .. May and August, **1883**	Blue, green, and silvery sun, persistent corona, and remarkable coloured twilights.
St. Augustin, Alaska .. October 6, **1883**	At about 8 a.m., a violent eruption split the mountain in two from peak to base.
Tarawera, New Zealand June 10, 1886	
Etna .. .. May 21, 1886	At 11 a.m. on May 21, height of smoke column 8 kilos.; on May 24, height about 14 kilos. (say 9 miles). Since May 22 the vapours spread over the eastern, and then over the whole horizon of Palermo. On June 3 fog prevailed over the district, making the sun invisible, and from May 29 to June 3, Italy from south to north was invaded by mist. Afterwards, the sun on rising was purple-red and reddish-yellow, and at about 30° was neutral grey. There were reddish-yellow afterglows. (Professor Riccò, 'Nature,' August 26, 1886.)

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* "The Volcanic Eruptions in Iceland in 1874 and 1875." By Captain BURTON. 'Proc. Roy. Soc. Edinburgh,' 1875–76.

From the foregoing list it appears that during the 250 years from 1500 to 1749 there were 65 years in which eruptions were recorded, excluding cases of prolonged and moderate activity lasting over several years. There were five years in which remarkably red skies were recorded in Denmark and Scandinavia, and all these coincided with periods of volcanic activity. In two of the five years there had been eruptions in Iceland; in one a great eruption in Japan; in one an eruption of Pichincha, Andes; and in one the only recorded former eruption of Krakatoa. In this last case the appearance of the sky must have greatly resembled the phenomena of 1883, for the entire sky was filled with blood-red light long before the sun rose, and, as happened in 1883 in India, Italy, and other countries, the people were terribly alarmed. In four years dry fogs or red skies occurred in Europe, without any traceable connection with volcanic eruptions; and, on the other hand, some great eruptions, such as those of 1693 and 1694, do not seem to have been followed by remarkable atmospheric phenomena.

During the 250 years there were nine years in which eruptions of great magnitude are known to have taken place, and in three of these years Denmark was affected by appearances, two of which certainly were of the character of after-glows, while the third is doubtful.

In the 137 years from 1750 to 1886 the number of years of eruptions was 90. In 26 years fine sunsets or remarkable twilight colourations were recorded; of these 26 years, 25 were years of volcanic eruptions, and, as a rule, the phenomena were noticed within five or six months after the eruptions. There were 25[*] years, at least, of eruptions of great magnitude, and of these 16 seem to have been followed by unusual redness in the twilight or brightness after sunset, sufficient to attract notice and to be recorded in Europe, within six months of the eruptions.

The number of days in the years, 1810 to 1820, inclusive,[†] on which red sunsets, luminous twilights, &c., were noted by **Howard**, are as follows:—

1810	4	1816	5
1811	33	1817	18
1812	17	1818	23
1813	31	1819	2
1814	21	1820	2
1815	24		

The years of eruptions among these were 1811, 1812, 1813, 1814, 1815, 1818, 1819, 1820. These figures, therefore, do not show any great preponderance of twilight phenomena in the years of eruptions. But many of the observations refer simply to cirri or cirro-cumuli coloured red by the setting sun and other cloud

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[*] Namely 1755, 1766, 1772, 1779, 1783, 1785, 1794, 1811, 1812, 1814, 1815, 1818, 1821, 1822, 1830, 1831, 1835, 1837, 1845, 1846, 1855, 1858, 1872, 1875, 1883.

[†] Howard's observations are more detailed for this than for any other period.

illuminations such as occur in all years. If we take only those years in which the sky itself is stated to have been much coloured, or in which there was a succession of highly-coloured sunsets, or in which the redness is stated to have lasted long, we find them to be the following: 1811, 1812, 1813, 1814, 1815, 1818. The sum of all the coloured twilights, &c., according to the above list, in these years, is 149, while in the remaining five years the sum is 31. Now, the number of eruptions in the first-named six years was 14, and in the remaining five years only four. The years of great eruptions were 1811, 1812, 1814, 1815, 1818, and in these years 118 twilight colourations, &c., were observed, while in the remaining six years 62 of these phenomena were noted; and exactly half of these 62 colourations were in 1813, during the period from the end of May to the end of December, which corresponds with the time during which Vesuvius was active.*

Of the period since 1750, thirteen years may be named as specially marked by numerous widespread or great eruptions, viz., 1755, 1766, 1772, 1783, 1794, 1815, 1818, 1821, 1822, 1831, 1846, 1872, and 1883. In eleven of these years the sky was unusually red in the twilights, or at least some remark on fine sunsets has been found recorded, as in 1822 and 1872.

In 1783, 1831, and 1883, the sun was seen rayless, or like the moon in some parts of the world, and in these years the sunset after-glows were most conspicuous and long-enduring. The blue sun of 1821 does not appear to have immediately followed any recorded eruption, or to have been associated with red twilights.

Red twilights may very probably have been recorded in years other than those mentioned in the above list, but the sources of information are few, and some of the manuscripts are scarcely legible.

It will be noticed that in the three instances of eruptions at the Azores, a bright or coloured twilight was observed in England within a week. Also that there was a striking coloured twilight nine days after the eruption at St. Vincent in 1812. The products of the eruption in Iceland in 1845 seem to have affected the atmosphere of the south of England in a similar manner five days after it took place. The sky in Switzerland seems to have been unusually red after sunset only a few days after the violent eruption of Hecla on April 15th, 1846. After the great eruption of Skaptar Jökull in 1783, Western and Central Europe were apparently affected in about eight or nine days On two occasions the atmosphere over England seems to have been affected about five or six days after eruptions of Vesuvius and Etna. There are indications that after eruptions the sky at long distances becomes quickly covered by cirrus haze or linear cirri, as on July 27, 1823, and September 2, 1845. The fall of ashes at the Orkney Islands on the latter date proves the great rapidity with which upper currents transport these products. In 1875, dust fell in Norway on the day of the eruption of Vatna Jökull, in Iceland.

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* Ménard de la Groye, 'Journal de Phys.,' vols. lxxx. and lxxxi.

Several instances illustrating the relation between the presence of dust and exceptional colouration, both of the sky and of the sun, have already been given in Section I. (c), pp. 213, 214.

Notes respecting detailed Accounts of Twilight Phenomena in some particulars similar to those of 1883, seen on former occasions and in various circumstances.

M. NECKER (in the 'Bibliothèque Universelle,' tome 23, 1839, p. 374) gives a valuable account of the crépuscule, and a table of the times when the second glow (*Alpenglüh*) disappeared after sunset on the high mountains of the Alps. M. DE LA RIVE also contributes a paper on the same subject (see pp. 355 and 383). At 27 minutes after sunset the top of Mont Blanc alone is red, and glows intensely like a red-hot coal; at 29 minutes past sunset (at Geneva) the light leaves Mont Blanc; then the snowy top assumes the pale cadaverous tint called *Leichenfarbe*, and after 4 or 5 minutes again turns rosy. M. NECKER attributes the effects to contrast of the snow with the first unilluminated and then illuminated sky behind it; so that when the first glow of the sky has left the eastern horizon Mont Blanc appears rosy; then, when the second glow rises up, appears grey, and when that has left the eastern horizon again appears rosy. The red vapours continue to rise in the sky (from the east) till 42 minutes after sunset (Geneva), then the whole east, up to the zenith, is dark. The time after sunset at which the second glow disappeared on the high Alps varied from 12 to 45 minutes, but from October 16th to 21st, 1837, it was 1 hr. 36 mins., and in June, 1834, a little over an hour. In the period from June to September, the glow left the east quarter at 42¾ minutes after sunset, on an average; from September to December at 30 minutes; from October to February, 35 minutes. "The red glow jumps across the zenith and is very seldom visible there." The red is seen across the zenith only when the vapours are unusually dense.

DE LA RIVE says that rays usually refracted become reflected when they pass from a denser and colder stratum to a warmer and lighter, such as sometimes exists in the upper atmosphere. On October 7th, 1837, at Geneva, the glow was superb; and on July 12th, 1834, the whole sky was coloured.

In 'Comptes Rendus' (xlviii., 1859, p. 109), M. LIAIS gives an excellent account of observations made by him in a voyage to Rio Janeiro from July 16th to 22nd, 1858. Near Cape Verde the sky was greyish in the daytime and the sun pale; the sun disappeared above the horizon in a hazy stratum. After this, in sailing south, the sky became clearer, and near the Equator twilight glows were well seen. Almost immediately after sunset, a rose colour shows itself in the east, and 11 minutes afterwards appeared in the west. In the east there is now a grey-blue or grey-green segment on the horizon, and in the west a white segment on the horizon; 8 minutes after its appearance in the west it ceases in the east. There is then a gradual descent of the rosy arc to the west horizon, and it sets when the sun is 11° 42′ below the horizon. When the first rosy arc is near setting, a second comes almost simultaneously at east and west, and then retires from east, passes to west, and is seen north and south; then the first rosy arc sets, and there remains the second rosy arc in the west, with a white segment below it. This sets when the sun is 18° 18′ below the horizon and becomes more and more red. At sunrise, the secondary glow began with the sun at 17° 22′, the primary with the sun at 10° 50′ below the horizon.

In Poggendorff's 'Annalen' (vol. cxlv., 1872, p. 196), BURKHART-JEZLER contributes a very interesting and detailed account of the *arrebol,* or twilight glow, on the east coast of South America, already quoted on p. 342.

The coast of Peru and the ocean westwards are remarkable for their sky effects, as testified by Colonel STUART WORTLEY,* and by STEWART ELLIS in his 'Voyage to the Sandwich Islands,' in the following passage :—

"We are now (15° S. 96° W.) off the coast of Peru, and have been delighted with the beauty of the sky and clouds, which is here very peculiar, and I should think unrivalled in any part of the world. Towards evening and in the morning I have seen at the same time clouds of almost every colour in different parts of the heavens, and of hues I never beheld there before; for instance, a rich and perfect green, amber, and carmine, while the hemisphere around the rising or setting sun has been one blaze of glory. Last night the tinge on the ocean was of a perfect blood colour, occasioned by the reflection of a fleecy veil of crimson clouds, stretched over the greater part of the heavens; the appearance was so singular as to cause us almost to shrink from it, as from something supernatural."

F. A. ROLLO RUSSELL.

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* Letter dated December 13th, in 'Times' of December 18th, 1883.

PART IV., SECTION VI.

Individual Opinions expressed and Hypotheses suggested to account for the abnormal Optical Phenomena of 1883–4–5.

By Mr. E. Douglas Archibald.

In this section we shall endeavour as far as possible to give a general, but concise, *résumé* of the principal opinions put forward regarding the nature and origin of the remarkable optical phenomena which were seen throughout the globe for some considerable period after their general commencement in August, 1883.

As the twilight glows were the phenomena which attracted most attention, and we have already given some account of the opinions entertained regarding the corona, blue and green suns, and cloud-haze, in the sections in which they are specially described, we shall here deal mainly with the subject of the twilight glows, though the opinions often embrace the entire series of phenomena and their possible cause or causes.

In dealing with the opinions we shall divide them into two groups—

(A.) Those which regard the phenomena as due to causes other than volcanic;

(B.) Those which regard them as the sequel to a great volcanic eruption, such as that of Krakatoa on August 26th and 27th, 1883.

Some persons criticise the volcanic theory adversely, without suggesting any other hypothesis. These we shall include in Group A.

Group A.

A writer in the 'English Mechanic,' December 26th, 1883, summarily disposes of the volcanic dust theory as follows :—

(1.) The assumed path of the dust violates the well-known course of atmospheric currents.

(2.) The first snowfall would bring it down.

(3.) We must believe that the dust travelled 200 miles per hour without producing a cyclone.*

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* It would be obviously unnecessary to notice all such tentative arguments, but we may say that there is no evidence to show that the material travelled at a rate of more than half of that here stated, or that it lay as low as the ordinary clouds.

M. ALLUARD,* thinks that the phenomena are due to needles of ice, and ascribes them to local causes.

[He was perhaps not aware of their universality.]

Mr. A. C. RANYARD † says that he is inclined to attribute the phenomena to a cosmical origin, and after citing certain facts regarding the diurnal character of the glows, goes on to remark that it is, therefore, evident that there must be finely-divided particles of matter suspended at a considerably greater height than usual in the atmosphere, and the question arises—Is this matter condensed aqueous vapour, is it volcanic dust from the great eruption of Krakatoa in the Malay Archipelago which occurred at the end of August, or does this dust come from outer space?

As to the first hypothesis, the meteorological conditions at the earth's surface have not been strikingly uniform over the area within which the remarkable sunsets have been observed; and there has been no widespread and exceptionally great downpour of rain, such as might have been expected if the amount of aqueous vapour in the atmosphere over a whole hemisphere of the earth had been much larger than usual.

The date of the great eruption of Krakatoa at first sight seems to be in favour of the volcanic dust hypothesis. In ordinary circumstances the vapours from such volcanoes as Etna and Vesuvius do not reach any great altitude. Possibly the cloud laden with volcanic dust, formed by a volcano near the Equator, might be carried upward by the heated air which gives rise to the trade winds; but in the northern hemisphere, the trade winds blow from a south-westerly direction; and this theory will not account for the carriage of dust to India, which lies to the north-west of Java, or to South Africa, which lies in a south-westerly direction. . . . It seems improbable that terrestrial dust should be carried upwards by the wind and distributed over a whole hemisphere. It may be suggested that dust was on this occasion projected by the volcanic forces to a much greater altitude than that reached by dust from the Sahara [which he says reaches Rome and Florence occasionally], but dust projected with great velocity would be rapidly stopped by the resistance of the atmosphere, and would not, unless borne away by the wind, be carried so far as stones and large masses of scoriæ.

It will hardly be suggested that the volcanic cloud over Krakatoa was carried upwards by the heat of the eruption, and spread outwards over a whole hemisphere, drifting against the prevailing winds to India and South Africa. But the volcanic theory is completely negatived by the observation of the blue sun setting in the fiery heavens, as seen from Trinidad on September 2nd (near to the centre of the opposite hemisphere from the Krakatoa eruption); for it cannot be supposed that the

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* 'Comptes Rendus,' xcvii., p. 161, *et seq.*

† 'Knowledge,' December 7th, 1883.

volcanic matter was carried half round the earth in the period of seven days which elapsed between August 26th and September 2nd. The dust was more probably meteoric dust: and the earth might have encountered a cloud of dust in space just before September 2nd, etc. Further on he says, "I imagine that the whole of the phenomenon observed may be accounted for by the mere presence in the upper regions of the atmosphere of a larger amount of dust than is ordinarily suspended there."

We have quoted the above opinion *in extenso*, as it represents very fairly the main objections which have been raised against the volcanic dust theory. We shall subsequently discuss these objections with others in Section VII., which gives a general analysis of the whole question.

M. A. LANCASTER, in 'Ciel et Terre,'* urges the following objections to the dust theory:—

(1.) That the amount of dust ejected would be too small to cause the phenomena.

(2.) That as there are ascending and descending currents in the atmosphere, the dust would be affected by these currents and exhibit itself at different levels instead of remaining apparently at one. He thinks that the effects are more probably due to ice-spiculæ, which may have been formed of water driven into the air by Krakatoa.

Professor MICHIE SMITH † says that the fact of the green sun appearing all over Ceylon and South India on the same day, and not at Rangoon and the Andamans, is against the dust theory. He also points out the following difficulties in the way of accepting the volcanic dust theory for the twilight glows and green sun; and distinguishes the extra-tropical twilight glows from the green sun and the attendant lurid glows within the tropics by the following characteristics:—

(1.) The spectra were totally different. In the latter case the red end was unusually free from absorption. A, α, and B, stood out clearly, the rain-band was slight, and the low sun bands were strong. This contrasts in every way with the spectrum of the green sun already given (referred to under blue and green sun section). ‡

(2.) The general appearances of the sunsets were quite different, the sunsets accompanying the green sun were lurid, and the horizon was so misty that stars were

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* 'Les Lueurs Crépusculaires,' page 553, February 15th, 1884.

† 'Nature,' vol. xxix. (1884), p. 38.

‡ We must here observe that, although Professor PIAZZI SMYTH, to whose spectroscopic observations on the twilight glows in Scotland Professor MICHIE SMITH evidently alludes, said, in his article in 'Nature,' vol. xxix. (1883), p. 150, December 13th, that the red end of the spectrum was practically unimpeded; and that the dry-air band was at an immense maximum; in a subsequent article, September, 1884, referred to under Section on the Corona (see *ante*, p. 253), he notices a marked absorption both at the red and violet ends, similar to that observed by Professor MICHIE SMITH.

lost in it; the subsequent sunsets (we imagine he refers mainly to those in the extra-tropics) were remarkable for the play of delicate tints, the rose-coloured after-glow, and the unusual clearness of the horizon.

Then, after mentioning three possible hypotheses which might explain the phenomena, viz.:

Volcanic dust from Krakatoa;
An abnormal amount of aqueous vapour;
Meteoric dust;

he puts forward against the volcanic dust theory the objections that there is (*a*) no proof of currents existing of such velocity as to account for the transmission of the blue and green suns along the Equator at the speed required by the dates; (*b*) the length of time which the dust took to reach India and Ceylon; (*c*) the variations of the phenomenon.

In favour of the aqueous vapour theory (for the green suns alone) he notices the fact of the rain-bands being particularly well marked, and also the general absorption in the red is cited.* Also the fact that a similar green sun has been seen through the thick clouds of a thunderstorm, and through the vapour escaping from the funnel of a steamer. He does not incline to view favourably the cosmical dust, or any solely dust hypothesis, owing to the slight decrease noticed in the solar radiation; and, finally, he winds up by saying, "We must, therefore, I think, give up any theory involving the presence of sufficient dust to render the sun green. Whether or not the following sunset glows were due to dust, I cannot discuss here; but I would point out that an amount of dust sufficient to produce these effects would probably not materially affect the transparency of the atmosphere."

Professor H. A. HAZEN † puts forward aqueous vapour in unusual quantity in the upper regions as a cause of the twilight glows, and cites the generally saturated state of the air on mountain peaks, as showing that aqueous vapour exists in large quantity at great heights, possibly as ice-spiculæ in the present case. Also unusual electrical action (based on Professor MICHIE SMITH's observations) is cited as a possible cause. Finally, the vapour is assumed to exist, for want of any known cause. He then shows that ice-spiculæ would account for the stars being seen through the haze. He says, also, that the persistence of the glows is favourable to the aqueous vapour theory, and endeavours to make out that most of the glows have been seen only in front of an area of high barometer; but he allows, at the same time, that this might be due to the greater clearness of the air in front of such areas.

He adds:—"The most serious objection yet advanced has been that the rain-band spectroscope shows an entire absence of watery vapour." This difficulty, however, is

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* This would, of course, leave the twilight glows and other phenomena in extra-tropical regions to be explained by some other hypothesis.

† 'American Journal of Science,' vol. xxvii., pp. 201–212.

satisfactorily got over, according to Professor HAZEN, by the fact "that Mr. CORY'S investigations indicate that, when vapour is at a low temperature and transformed into ice-crystals, it does not produce a rain-band, and other observations show that at high temperatures the spectroscope does not reveal anything as to the nature of the substances in the regions far above the lower stations containing water. An abundance of frost particles would not affect the spectrum."

He then summarises the objections to the volcanic dust theory as follows ;—

(1.) "There must have been sufficient material to cover more than 135,000,000 square miles :"

(2.) "There must have been currents of nearly equal force acting in opposite directions at the same height in the atmosphere ;—an impossible condition :"

(3.) "The upper currents must have had sufficient force to carry the ashes 12,000 miles in 150 hours, or at a rate of 80 miles an hour towards the west."

He adds :—"The velocities of air currents at great heights are probably slight, and possibly there is a gradual diminution in velocity with increasing height." *

(4.) "That the ashes must have been mechanically distributed along a belt near the Equator, and afterwards, without addition, except possibly of a meagre character, the currents must have been sufficiently uniform over the whole earth to have borne them north and south to above 45° latitude, and this is well nigh incredible."

(5.) That the intermittent nature of the phenomenon precludes the idea of a dust envelope.

(6.) That ashes are opaque, while the appearances indicate great transparency.

LAS VEGAS † attributes the appearances to the comet of 1882, which broke up before September 9th, the matter composing which, uniting with the sun, produced sulphide of carbon, which is supposed to have caused the appearances.

A correspondent of the 'Scientific American'‡ says that the glows were due to the red spot on Jupiter having reached the earth!

Mr. J. E. FRASER § thinks that they were caused by a cyclone in the sun's photosphere!

Professor H. KRONE || thinks that an unusual amount of aqueous vapour was the cause.

Dr. JULIUS HANN¶ tentatively does not admit the volcanic dust hypothesis, owing to the insufficiency of the amount of dust, which, if it is assumed to have come from Krakatoa, he calculates could have formed a stratum only ·01 mm. thick (about ·0004 in.).

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* This is totally at variance with the results of observation.—E. D. A.

† 'Cosmos,' 3rd Series, t. vii., pp. 344–9.

‡ 'Knowledge,' March 14th, 1884.

§ 'British Daily Mail,' August 20th.

|| 'Met. Zeitschrift,' vol. i., p. 277.

¶ 'Zeits. für Meteor.,' Bd. xix. (1884), p. 78.

Mr. R. L. J. Ellery, F.R.S.,[*] of Melbourne, objects to the volcanic dust theory on the ground (1) of the difficulty of conceiving how a local eruption could produce such wide-spread effects; and (2) that a spectroscopic examination showed great development of the telluric and atmospheric lines, especially those shown by M. Janssen to be due to aqueous vapour in certain conditions in the higher strata. He thinks that the eruption may, however, have indirectly produced certain chemical changes in the upper strata extending over a wider area than the direct effects themselves.

Dr. Ragona[†] upholds the view that the phenomena are due to ice-spiculæ (he does not say whence the vapour forming the ice-spiculæ is derived), to which he thinks that ordinary red twilights also are due. He also points out their similarity to the aurora.

Mr. Proctor[‡] objects to the hypothesis that Krakatoa dust explains the blue and green suns, on the grounds (1) that the material required would be more than was expelled; (2) that while the dust must have travelled about 75 miles an hour along the Equator, we must suppose it to have travelled quite leisurely towards Ceylon and South India.[§]

Rev. Professor S. Haughton, F.R.S.,[||] after stating the computed height of the twilight-producing atmosphere from a solar depression = 18° at the end of twilight to be

40	miles	on the hypothesis of	one	reflection,
12	,,	,,	two	,,
5	,,	,,	three	,,
3	,,	,,	four	,,

proceeds to examine Mr. Bishop's observation at Honolulu on September 5th, and finds the solar depression at the end of this sunset to be 18° 22′; from which he concludes that "This indicates twilight phenomena intensified by some unusual cause, but does not denote an extension of twilight reflection into regions of the air higher than the time-honoured traditional 40 miles."

Professor Haughton, however, overlooks the very important fact that the time-honoured traditional 18° is the solar depression at the end of the ordinary white astronomical twilight, while the unusual glows under discussion, including that observed by Mr. Bishop, were red up to their final disappearance. This latter point, we take it, shows the presence of particles capable of reflecting or dispersing *red* light

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[*] 'Nature,' vol. xxix. (1884), p. 548.

[†] 'R. Accademia di Scienze,' Modena, January 15th, 1884.

[‡] 'Knowledge,' December 26th, 1883.

[§] This apparently leisurely march towards South India is explained by the main stream only barely skirting Ceylon on its first circuit of the globe, and reaching India after it had widened in latitude, at the commencement of its *second* circuit.

[||] Proc. Royal Soc. of Dublin. Read January 21st, 1884.

in regions of the atmosphere as lofty as those which produce the ordinary white astronomical twilight.

He then goes on to say: "We know that the phenomena at Honolulu on the 5th of September were unusual twilight phenomena, but had no connection with reflection from the upper regions of the air. In point of fact, my calculation of the sun's position disproves the presence of dust, or any reflecting substances in the upper air."

We fail to follow Professor HAUGHTON here. An elevation of 40 miles, or even 12 miles, may surely be considered the upper air. Physically and meteorologically speaking, the air may be said to cease about the former level, the pressure at 17 miles being only about 1 inch of mercury. Professor HAUGHTON, moreover, regards the speed of 82 miles an hour* required for the volcanic material to have reached Honolulu, assuming it to have started from Krakatoa on August 27th, as "absolutely incredible;" but surely nothing can be said to be absolutely incredible in science until it has been proved to be absolutely impossible.

M. PELAGAUD, who observed the twilight glows at Réunion on September 8th, and apparently thenceforward up to April, 1884, after a prolonged examination, arrived at the conclusion that the phenomenon was nothing else than an effect of electricity. "The great cyclones," he says, "which have disturbed all these parts suffice to exclude all hypothesis of solid particles having been suspended in the upper regions of the atmosphere† for more than six months."‡ Besides, on one occasion, he saw the red mist on its first appearance spread itself over a layer of cirro-stratus, probably very elevated.§

M. G. A. HIRN || does not express himself decidedly for or against the volcanic hypothesis; but, from his observations of the height of the glow-stratum (which we have shown in Section IV. are founded on an erroneous hypothesis, and are thus vastly in excess of all others), concludes that "the matter (either vapour or dust) illuminated by the solar rays and producing the twilight glows, was, at all events for the most part, beyond the terrestrial atmosphere, and in all cases at heights where one has never observed cirrus or a trace of water vapour."¶

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* About the same as that deduced in Section II. from all the observations.

† Here, in direct contrast to Professor HAUGHTON, the *upper* air is brought down to the cyclone level.—E. D. A.

‡ 'L'Année Scientifique,' 1885, p. 43.

§ It is instructive to note that a little lower down the same page from which the above extract has been taken, an account is given of pumice having arrived on the shores of Réunion, which "was indubitably traced to the eruption of Krakatoa."

|| 'L'Année Scientifique, 1885, p. 45.

¶ The erroneous character of the hypothesis on which M. HIRN bases his calculation of the height of the stratum would alone be sufficient to condemn his view; but, besides this, the succession of dates of the first appearances of the blue sun and twilight glows near the Equator, and the precise rate of transmission, completely dispose of the extra-terrestrial position of the material.

M. VAN SANDICK,[*] who was an eye witness of the Krakatoa eruption, after studying the results given by Mr. VERBEEK, discusses the question of the possibility of the matters erupted by Krakatoa having been able to produce the effects which were witnessed, and arrives at the conclusion that "the phenomena were due to ice-crystals derived from aqueous vapour which congealed in these lofty regions. That the vapour itself would be due to the relatively mild temperature which prevailed during the winter of 1883–4, and that the needles of ice floating in these lofty regions would explain perfectly the extraordinary colour effects which exhibited themselves long before the rising and after the setting of the sun."

We give M. VAN SANDICK's objections below :—

"Le jet éruptif atteignit 20 kilomètres de hauteur, 18 kilomètres cubes de matières furent lancées par le volcan. Le poids de ces matières projetées est au minimum de 36,000 milliards de kilogrammes. Les deux tiers de ce poids ont été projetés sur une surface circulaire de 15 kilomètres de rayon. Ce sont donc 12,000 milliards de kilogrammes qui ont été projetés dans l'atmosphère. En donnant seulement 1 kilomètre d'épaisseur à la couche sphérique renfermant les cendres projetées on a pour le volume de cette couche 511 millions 558 mille 55 kilomètres cubes. Le rapport du volume des cendres dans l'air à celui de cette couche dans laquelle elles sont disséminées est plus petit que 1 vingt-huit millionième. D'après cela ce serait 1 millimètre cube de cendres répandues dans 28 litres d'air ou bien 1 centimètre cube de cendres dans 28 mètres cubes d'air. La densité de cette cendre ainsi disseminée serait 1 quatorze-millionième par rapport à celle de l'eau et par rapport de l'air à la surface terrestre cette densité des cendres éparpillées en serait les 55 millionièmes. Cela correspond à une pression de 42 millièmes de millimètre de mercure dans le baromètre ou à une colonne d'eau de 57 centièmes de millimètre de hauteur.

"En presence de ces chiffres peut on attribuer la cause des phénomènes crépusculaires observés partout pendant des mois à des particules de cendres volcaniques en suspension dans les régions supérieures de l'atmosphère ? Nous ne le pensons pas."

The editor of 'L'Année Scientifique,' in the volume for 1886,[†] continues the above argument, and maintains that "if at the commencement of the phenomenon the pressure of the ashes could sustain a column of water of only the fraction of a millimetre, supposing them to be spread in a gaseous layer only one kilometre in thickness, we must conclude that at the end of 22 months the thickness of the layer of air containing the same dust reached from 40 to 50 kilometres (24·8 to 31 miles.)[‡]

"This conclusion would give us for the powdery matter which acted, a cubic millimetre (·00005 cubic inch) of ashes in more than 1,100 cubic metres of air (38,786 cubic feet), or 1,100,000 litres, representing a cube whose side would exceed 10 metres (32·8 feet). And it is in this volume that so small a cube of dust, having a side of one millimetre, could occasion the luminous effects of the twilight glows. In truth, it is not possible to maintain such an hypothesis." The

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[*] 'L'Année Scientifique,' 1885, p. 50.

[†] Page 38.

[‡] This assumes a rate of fall nearly four times as great as that which we have determined in Section VII.

writer then proceeds to ascribe the phenomena to crystals of ice, or to some cosmical matter detached from the zodiacal light, or having some other origin. It is noteworthy that neither here nor elsewhere is the vapour, from which the crystals were formed, directly traced to a volcanic source, or indeed to any unusual *terrestrial* cause.

M. L. CRULS[*] says that the hypothesis of a dry fog, to explain the phenomena observed at Rio Janeiro which he propounded at first, he was obliged to abandon when, later on, he noticed the obscuration of the sun by the smoke-like haze. He considered that the various phases of the twilight glows, the first and second rosy arches, the hour of their appearance and disappearance, showed them to be atmospheric and of the same character as ordinary twilight, possibly lengthened by the presence of meteoric particles.[†]

The above are some of the principal opinions which we have seen adverse to the volcanic dust or volcanic vapour and dust theory, and also the chief hypotheses framed to account otherwise for the phenomena. It cannot be complete, and it would be beyond our scope, and unnecessary, to extend it further. The main feature of this summary is, that it shows a good deal of destructive criticism, but very little constructive or reasonable hypothesis. Disregarding such very improbable hypotheses as those of the red spot on Jupiter, cometary action, and electrical action (always a *dernier ressort* of a section of physicists), we find only two rational hypotheses in which volcanic action is not necessarily postulated, viz. : (1) Meteoric dust ; (2) an unusual amount of aqueous vapour in the upper regions. Each of these hypotheses requires the intervention of some unusual occurrence unconnected with terrestrial volcanic action, and not a single fact has yet been suggested to prove that anything else has happened to cause an unusual quantity of either dust or vapour, or both together.

Group B.

We now proceed to give some account of the opinions of those who support the volcanic theory in some form or other.

Rev. SERENO E. BISHOP[‡] was the first observer in the tropics who noticed the conjoint arrival of all the optical phenomena at Honolulu on September 5th, and particularly the coronal appendage which, with the peculiar haze, forms the most certain link between the tropical and extra-tropical appearances.

He was also one of the first to uphold the hypothesis that these appearances were all traceable to the August eruption of Krakatoa, and he bases his opinion on the following considerations :—

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[*] Imperial Observatory, Rio de Janeiro, 'Comptes Rendus,' xcviii., pp. 1013–6.

[†] We have thought it best to insert this here, though the author leaves the question of the precise cause *sub judice*.

[‡] (1.) "Equatorial Smoke Stream from Krakatoa," 'Hawaiian Monthly,' May, 1884. (2.) "Third Warner Prize Essay," 'American Meteorological Journal,' July and August, 1886.

(1.) The consistent rate of progress of the phenomena westwards from the Javan area, as shown by the successive dates of first appearances.

(2.) The absence of any positive evidence in favour of cosmic and meteoric influences, and the narrow localisation of the haze at first in the tropical zone.

(3.) The unprecedented character of the eruption as regards area of detonations, dust-fall, air waves, and water waves.

(4.) The probability of ultra-microscopic dust projected to a height of at least 40 miles, being capable of remaining suspended for years.

Dr. MELDRUM, F.R.S.,* after describing the eruption of Krakatoa, the detonations heard at Diego Garcia and Rodriguez, nearly 3,000 English miles from Krakatoa, and the dust which was reported to have fallen in various parts of the Indian Ocean, glides naturally into the view that the fact of the sun being partially obscured at those places on August 27th was evidently traceable to Krakatoa.

He cites also the fact of the sun appearing light green on May 20th from the *Actæa*, and like dull silver on May 21st, as a proof that effects similar to those following the major eruptions at great distances were in the vicinity of the volcano directly traceable to its minor eruptions in May.

The suspension of the dust he explains by the lower atmosphere being possibly denser than the dust in suspension.

Miss ISIS POGSON † attributes the phenomena to Krakatoa, but supposes the agent which caused them to be not dust, but sulphurous vapours. [This is similar to the idea of Mr. F. L. CLARKE, of Honolulu.]

Mr. G. J. SYMONS, F.R.S.,‡ Mr. J. EDMUND CLARK,§ and Mr. J. N. LOCKYER, F.R.S.,|| were among the first in Europe who suggested the unparalleled eruption of Krakatoa on August 27th as the probable cause of the remarkable optical phenomena which succeeded it. Mr. LOCKYER founds his views on the following bases:—(1) An unusual occurrence, such as the eruption of Krakatoa, may, through the agency of ordinary causes, produce unusual effects; (2) the line of sunsets, green suns, &c., apparently originating from the neighbourhood of Java, and their gradual progression westwards; (3) the various colourations of the sun, showing evidence of differences in the sizes of the particles composing the absorbing medium, such as would be likely to occur in the case of volcanic dust thrown into the higher regions of the atmosphere.

Mr. J. E. CLARK¶ says:—"To me the glare never seemed as if reflected from cirrus clouds. It was much more like that from the smoke-originated clouds of

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* 'Proc. Met. Soc. Mauritius,' October 27th, 1883; May 22nd, 1884.

† 'Ceylon Observer,' September 18th, 1883.

‡ Letter, dated November 29th, in 'Times,' December 1st, 1883.

§ Letter, dated December 3rd, in 'Nature,' December 6th, 1883.

|| Article in 'Times,' December 8th, 1883.

¶ 'Nature,' vol. xxix. (1883), p. 130, and further remarks in 'Second Warner Prize Essay,' 1886.

manufacturing districts. The day effect was evidently from the same cause as the after-glow. May it not help us to connect it with the green sun phenomenon of India? In that case the possible connection of the latter with the volcanic eruptions of Java assumes special interest," &c.

Mr. A. RINGWOOD[*] founds his argument in favour of the Krakatoa origin of the phenomena mainly on the apparently regular and repeated progressions of the coloured suns and twilight glows round the world near the Equator from the neighbourhood of Java. In tracing the path of the so-called "smoke stream," Mr. RINGWOOD assumes it to have made one complete revolution round the globe before it reached India. Afterwards, by assuming the stream to widen out as it progressed, and to continue revolving round the earth, he makes the extra-tropical observations fit in to the others. The average rate of the smoke stream within the tropics is 2,105 English miles per day for the Northern Hemisphere, and 2,031 English miles per day for the Southern Hemisphere. From all the observations a mean lag of 2,083 English miles per day, or 87 miles per hour, is inferred.

Mr. F. L. CLARKE, of Honolulu,[†] says:—"The effects were evidently due to solid particles in the air. . . . Tyndall says that blue colour in water is due to particles too small for detection by a microscope magnifying 100,000 times, and a haze may be formed by particles which a microscope will not reveal. Probably a large portion of the matter projected from Krakatoa was sulphurous acid gas. Admitting that the gas was sent up to a great height, it might be decomposed by the sun's rays with liberation of sulphur."

Mr. W. H. PREECE,[‡] F.R.S., thinks that the dust shot up from Krakatoa might have been electrified with the same sign as that of the earth, viz., negative: "Therefore, when the force of projection had exhausted itself, the cloud of matter would be subject to two other forces besides gravity: (1) the repulsion of the electrified earth; (2) the self-repulsion of each particle of electrified dust." The first would determine the tenuity of the cloud, and the second its lateral extension. He adds to this some examples of smoke spreading out in ordinary circumstances.

Dr. J. H. GLADSTONE, F.R.S.,[§] says:—"Clouds of meteoric dust are purely hypothetical, but clouds of volcanic dust are known phenomena. Spectroscopic observation of the glows [in the extra-tropics] show that the colour is not due to any great absorption by vapour in the atmosphere."

Mr. W. CROOKES, F.R.S.,[||] shows how the volcanic dust might remain suspended. He says:—"In a paper read before the Royal Society in 1879, I showed that at a

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[*] 'Nature,' vol. xxx. (1884), pp. 301–304. Paper read to the Canterbury Phil. Inst., New Zealand, May 1st, 1884.

[†] 'Honolulu Advertiser.'

[‡] 'Times,' December 12th, 1883.

[§] Letter, dated December 18th, in 'Times,' December, 1883.

[||] 'Nature,' vol. xxix. (1883), p. 181.

rarefaction of the millionth of an atmosphere two pieces of electrified gold-leaf repelled one another at a considerable angle for 13 months without loss of charge. Therefore, at a rarefaction of a millionth (corresponding to a height above the earth's surface of about 62 miles), air is a perfect non-conductor of statical electricity without interfering with the mutual repulsion of similarly electrified particles. When we bear in mind that the specific gravity of gold is five or six times that of the rock whose disruption formed the dust in question, and that the size of the individual particles of dust is certainly many thousand times smaller than my gold leaves, there is every reason to believe that electrified dust, when once projected 50 or 60 miles above the earth's surface, might remain there for years."

The Rev. W. C. Ley[*] favours the view that the phenomena were due to vapour and dust projected from Krakatoa, and winds up as follows :—"Granting the distance to which the vapour and dust were ejected from the bowels of Krakatoa to have been so great that the more rapidly rotating surface of the earth brought Panama under this vapour and dust in the space of less than a week, we have a gigantic pepper-box capable of condensing and congealing vapour which had long remained undisturbed in its serene heights. We do not need to call in the known currents of the atmosphere to explain the dispersion poleward, and therefore eastward, of the volcanic matter, gravitation alone accounting for the transmission of the particles down the inclined isobaric planes."

Mr. C. L. Prince,[†] Crowborough Observatory, says: "I could never accept the Krakatoa volcanic dust theory, but at the same time I do not hold the great eruption of Krakatoa to be unconnected with these phenomena. From the vast amount of terrestrial displacement occurrent, and the equally vast amount of sea-water which rushed into the chasm, an inconceivable quantity of steam, charged with the various saline ingredients of which sea-water is composed, was forced up to an extraordinary height, where, on account of a low temperature, it became suddenly crystallised," &c.

M. R. Radau[‡] says that the observed velocities of cirri have been as much as between 150 kilometres and 250 kilometres per hour (93 to 155 miles per hour), which would suffice to explain the transit of impurities from Java capable of causing the change in the sun's appearance at Réunion on August 27th.

M. P. J. Thirion[§] says: "Without alluding to the probable identity of the dust collected in Spain and in Holland with the ashes of Krakatoa, the agreement of the dates, the march of the phenomena pursuing paths all which start from the district of the Strait of Sunda, the succession of the crepuscular illuminations following upon the coloured sun, which was in turn preceded by the veiled sun, the darkness, and the rain of dust, force us to recognise their intimate connection with

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[*] 'Nature,' vol. xxix. (1883), p. 175.

[†] "The Phenomenal Sunsets," 'The Summary of a Meteorological Journal.'

[‡] 'American Journal,' vol. i., pp. 29–33.

[§] 'Les Lueurs Crépusculaires.'

one another. Is it possible to doubt that this extremely violent volcanic eruption has driven sufficent material into the atmosphere to produce these absorption phenomena? Would it be rash to affirm that Krakatoa has vomited more dust than the falling stars and aërolites furnish during many years, and who could estimate the infinitely larger mass of vapours and gases which have pulverised and transported this dust?" And he goes on to reject the cosmic dust and other theories, and to say that "dust, vapour, and ice will explain the ordinary phenomena and even the optical peculiarities of the glows; but only an exceptional ascension of vapour, ice, and dust from some centre, like the volcano of Krakatoa, will explain the exceptional and special features connected with the glows."

Professor J. LE CONTE,[*] of California, says:—"It seems scarcely necessary to invoke the repulsive agency of electricity to account for the persistent suspension of the volcanic dust, even in these regions of rarified air. If the attenuation be sufficiently great there will be no sensible subsidence of the dust particles. Minutely divided gold will remain suspended in water for months, and some forms of soluble mineral matter remain suspended in water for an almost indefinite period. Now, the dust particles forming the nuclei of condensation for fogs and cloud are absolutely ultra-microscopic in smallness; hence their suspension in rarefied air may be prolonged almost indefinitely. Moreover, it is possible that air may possess some viscosity, in which case the indefinitely attenuated dust particles might have no tendency to subside, and could be removed from the atmosphere only by those meteorological agencies, such as the condensation of vapour, which tend to augment their size."

M. A. WITZ[†] says: "The fine porphyrised powder of the richly augitic eruptive matter discharged by Vesuvius, contains fragments of crystals which are pale green by transmitted light and red by oblique reflected light. This dichroism would explain the green sun and the fiery [*embrasés*] horizons produced by refraction and reflection of the sun's rays in the lofty atmospheric regions."

Professor O. N. STODDARD,[‡] of Ohio, says that the second glow, being evidently a reflection of the first, the height of the reflecting layer is at no very great distance above the earth. He favours the view that it might be due to gases, such as chlorine, from the sea-water admitted into the volcano.

Mr. J. AITKEN,[§] in considering the cause of the remarkable sunsets, distinguishes between two theories: (1) an excess of aqueous vapour [he does not seem to entertain the possibility of this vapour having been derived from Krakatoa], and (2) volcanic dust from Krakatoa, or other volcanoes; and says:—"There seems to be a possibility of determining by observations which of these theories is the more probable. . . .

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[*] 'Nature,' vol. xxix. (1884), p. 403.

[†] "Coincidences entre les phénomènes observées en 1831 et en 1883," 'Comptes Rendus,' xcviii., p. 542.

[‡] 'Nature,' vol. xxix. (1884), p. 355.

[§] 'Proc. Roy. Soc. of Edinburgh,' January 21st, 1884.

If dust is the cause of these glowing colours, then there must be a display of the colours complementary to the reds; because dust acts, not by the selective absorption and destruction of the colours, but by a selective dispersion of them.

"The very small particles of dust in the atmosphere stop the direct course of the rays, and reflect them in all directions; but the dust particles are so very small, especially in the upper regions, that they are capable only of stopping, reflecting, or scattering the rays of the blue end of the spectrum; while the red rays pass on unchecked. Therefore, there ought to be somewhere in the sky a display of the colours of the blue end of the spectrum. From the observations which I have been able to make since this suggestion presented itself, I find that the display of blue and green colours is quite as prominent a feature of the late sunsets as is that of the reds." . . . . "These considerations seem to point to dust as the cause of the glowing colours of our late sunsets, as none of the colours are destroyed [or absorbed as would be the case if watery vapour were the medium], but are simply sifted out and assorted."

Baron von **Nordenskiöld**[*] concludes, from observations made at Stockholm (full details of which he hopes to give subsequently), that the sole cause of the remarkable sunsets is dust derived from the volcanic eruption in the Sunda Isles.

Professor **Kiessling**[†] makes the following remarks, specially on the twilight phenomena; though his researches relate to the blue suns and corona as well:—"The intensely bright twilight colours evidently necessitate the existence of a cloud formed of extremely minute, uniformly distributed, water molecules. The formation of this fine cloud pre-supposes the existence of a fine dust which is present in the air, and which rests immediately on the earth's surface . . . . It must be carried upwards in large quantities by the upwardly streaming air currents; while, during volcanic eruptions, it must be shot up to very great heights."

He attributes the twilight effects, on this assumption, to an excentric diffraction image caused by the sun's rays passing obliquely through a stratum, in which the size of the dust particles increases from above downwards. This can be experimentally imitated by allowing the edge of a cloud of dust molecules, such as those of sulphate of ammonia, to touch a plate of glass whose temperature decreases from above downwards. In this manner the succession of colours, orange, green, bluish-red, crimson-red, is obtained.

Mr. W. F. **Stanley**[‡] approaches the subject from considerations based on the amount and physical properties of the ejected dust. The millions of tons of fine

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[*] 'Comptes Rendus,' xcviii., January 21st, 1884.

[†] "Über den Einfluss. künstlich erzeugten Nebel auf direktes Sonnenlicht." 'Met. Zeitschrift,' March, April, 1884.

[‡] "On certain effects which may have been produced in the atmosphere by floating particles of volcanic matter from the eruption of Krakatoa and Mount St. Augustin."—'Quarterly Journal of the Roy. Met. Soc.,' July, 1884.

dust and steam projected in the case of this eruption were, he thinks, a *vera causa* for such abnormal atmospheric effects as were observed.

The principal grounds for his opinion that the twilight effects were due to volcanic dust are :—(1) The general constancy of the phenomena after they had commenced; which showed that what produced them did not change its state. This he considers to favour the idea that they were due to dust alone, and not to vapour. (2) An examination of dust which fell on the *Arabella*, about 1,140 English miles from Krakatoa, shows the dust to be made up chiefly of chips and thin plates of overblown pumice bubbles, which, by dispersion and reflection (from plates floating with their flat sides horizontal when the sun was at a low angle), would not only produce the effects which were seen, but, in forms analogous to, and thinner than, those which fell, would be capable of prolonged suspension.

Professor S. P. LANGLEY'S* views are stated below :—

"At first I supposed the sunset matter to be a local phenomenon; but when the reports showed it to have been visible all over the world it was obvious that we must look for some equally general cause. We know but two likely ones, and these have been already brought forward. One is the advent of an unusual amount of meteoric dust. While something over ten millions of meteorites are known to enter our atmosphere daily, which are dissipated in dust and vapour in the upper atmosphere, the total mass of these is small as compared with the bulk of the atmosphere itself, although absolutely large. It is difficult to state with precision what this amount is, but several lines of evidence lead us to think it is approximately not greatly less than 100 tons per diem, nor greatly more than 1,000 tons per diem. Taking the larger estimate as still below the truth, we must suppose an enormously greater accession than this to supply quantity sufficient to produce the phenomenon in question, and it is hardly possible to imagine such a meteoric inflow unaccompanied by visual phenomena in the form of 'shooting stars,' which would make its advent visible to all. Admitting, then, the possibility of meteoric influence, we must consider it to be nevertheless extremely improbable.

"There is another cause, which I understand has been suggested by Mr. LOCKYER —though I have not seen his article—which seems to be more acceptable, viz., that of volcanic dust; and in relation to this presence of dust in the entire atmosphere of this planet I can offer some little personal experience. In 1878 I was on the upper slopes of Mount Etna, in the volcanic wastes, three or four hours' journey above the zone of fertile ground. I passed a portion of the winter at that elevation engaged in studying the transparency of the earth's atmosphere. I was much impressed by the fact that here, on a site where the air is supposed to be as clear as anywhere in the world, at this considerable altitude, and where we were surrounded by snow-fields and deserts of black lava, the telescope showed that the air was filled with minute dust particles, which evidently had no relation to the local surroundings, but

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* 'New York Daily Tribune,' January 2, 1884. Communicated by Professor PIAZZI SMYTH.

apparently formed a portion of an envelope common to the whole earth. I was confirmed in this opinion by my recollection that Professor PIAZZI SMYTH, on the Peak of Teneriffe, in mid-ocean, saw these strata of dust rising to the height of over a mile, reaching out to the horizon in every direction, and so dense that they frequently hid a neighbouring island mountain, whose peak rose above them as if out of an upper sea. In 1881 I was on Mount Whitney, in Southern California, the highest peak in the United States, unless some of the Alaskan mountains can rival it. I had gone there with an expedition from the Alleghany Observatory, under the official direction of General HAZEN, of the Signal Service, and had camped at an altitude of 12,000 feet, with the special object of studying analogous phenomena. On ascending the peak of Whitney, from an altitude of nearly 15,000 feet, the eye looks to the east over one of the most barren regions in the world. Immediately at the foot of the mountain is the Inyo Desert, and on the east a range of mountains parallel to the Sierra Nevadas, but only about 10,000 feet in height. From the valley the atmosphere had appeared beautifully clear; but from this aërial height we looked down on what seemed a kind of level dust-ocean, invisible from below, but whose depth was six or seven thousand feet, as the upper portion only of the opposite mountain range rose clearly out of it. The colour of the light reflected to us from this dust-ocean was clearly red, and it stretched in every direction as far as the eye could reach, although there was no special wind or local cause for it. It was evidently like the dust seen in mid-ocean from the Peak of Teneriffe—something present all the time, and a permanent ingredient in the earth's atmosphere.

"At our own great elevation the sky was of a remarkably deep violet, and it seemed at first as if no dust was present in this upper air; but on getting, just at noon, in the edge of the shadow of a range of cliffs which rose 1,200 feet above us, the sky immediately about the sun took on a whitish hue. On scrutinising this through the telescope, it was found to be due to myriads of the minutest dust particles. I was here at a far greater height than the summit of Etna, with nothing around me except granite and snow-fields, and the presence of this dust in a comparatively calm air much impressed me. I mentioned it to Mr. CLARENCE KING, then Director of the United States Geological Surveys, who was one of the first to ascend Mount Whitney, and he informed me that this upper dust was probably due to the 'loess' of China, having been borne across the Pacific, and a quarter of the way around the world. We were at the summit of the continent, and the air which swept by us was unmingled with that of the lower regions of the earth's surface. Even at this great altitude the dust was perpetually present in the air, and I became confirmed in the opinion that there is a permanent dust shell inclosing the whole planet to a height certainly of about three miles (where direct observation has followed it), and not improbably to a height even greater; for we have no reason to suppose that the dust carried up from the earth's surface stops at the height to which we have ascended. The meteorites, which are consumed at an average height of 20 to 40 miles, must add somewhat to this. Our observations, with special apparatus, on Mount Whitney went to show that the red rays are transmitted with greatest facility through our air, and rendered it extremely probable that this has a very large share in the colours of a cloudless sky at sunset and sunrise, these colours depending largely upon the average size of the dust particles.

"It is especially worth notice that, as far as such observations go, we have no reason to doubt that the finer dust from the earth's surface is carried up to a surprising altitude. I speak here not of the grosser dust particles, but of those which are so fine as to be individually invisible, except in favouring circumstances, and which are so minute that they might be an almost unlimited time in settling to the ground, even if the atmosphere were to become perfectly quiet. I have not at hand any data for estimating the amount of dust thrown into the air by such eruptions as those which recently occurred in Java and Alaska. But it is quite certain, if the accounts we have are not exaggerated, that the former alone must have been counted by millions of tons, and must, in all probability, have exceeded in amount that contributed by meteorites during an entire year. Neither must it be supposed that this will at once sink to the surface again. Even the smoke of a conflagration so insignificant, compared with nature's scale, as the burning of Chicago was, according to Mr. CLARENCE KING, perceived on the Pacific coast; nor is there any improbability that I can see in supposing that the eruption at Krakatoa may have charged the atmosphere of the whole planet (or, at least, of a belt encircling it) for months with particles sufficiently large to scatter the rays of red light and partially absorb the others, and to produce the phenomenon that is now exciting so much public interest. We must not conclude that the cause of the phenomenon is certainly known; it is not. But I am inclined to think that there is not only no antecedent improbability that these volcanic eruptions on such an unprecedented scale are the cause, but that they are the most likely cause which we can assign."

M. CH. DUFOUR[*] thinks that the gas and dust expelled from Krakatoa during the cataclysm of August 27th, 1883, travelled (to Europe) by way of the Pacific Ocean, America, and the Atlantic, more than by India and Egypt. . . . "To support the idea that these crepuscular glows were due to substances expelled from Krakatoa, it has been said that no further back than in 1831 something similar took place after the volcanic phenomena which accompanied the appearance of the Isle of Julia;[†] but, besides, in 1831, there were certain dry fogs over a large part of Europe attributed to the same cause; and one might add that precisely a century before the Java catastrophies, in 1783, a large part of Europe and the Mediterranean basin were covered by a similar mist, slightly luminous during the night. This mist, very closely observed by DE SAUSSURE, remained nearly two months. In the fine days of

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[*] 'L'Année Scientifique,' 1884, p. 47.

[†] Another name for Graham's Island.

summer, from the shores of the Lake of Geneva, it was not possible to see the mountains of Savoy, distant only 14 or 15 kilometres (9 miles); and in the month of August, at 10 o'clock in the morning, the sun could be observed without difficulty by the naked eye. . . . These luminous mists have generally been attributed to the dust, or smoke, ejected by volcanoes during that period. It is true that, in 1884, we have had glows in the lofty regions of the atmosphere, and not fogs in the lower regions, but that is explained by the distance of the point of emission." [*]

Professor G. H. Stone, of Colorado,[†] refers to the twilight glows and associated phenomena as follows:—

(*a.*) "The glow[‡] may be due wholly to diffraction—1st: upon volcanic dust, mixed perhaps with other dust normally present in the air. The dull colour of the glow is in favour of this hypothesis; also the wonderful intensity of the glow immediately after the great volcanic eruptions of 1883.

"2ndly: The glow is caused by diffraction upon both volcanic dust and extremely small ice-crystals or grains; the colour due to the dust being nearly constant and rather faint, that from the ice varying according to the conditions of precipitation.

"3rdly: The glow may be due to ice particles alone. Both the white and the iridescent halos[§] are undoubtedly caused by refraction, reflection, and dispersion by ice crystals. It remains to be proved that ice particles, or grains, may be of such size or shape that they can give a brown diffraction colour.

"4thly: Some or all of the dust particles at high elevations in the air may become coated with ice, and the glow may be due to diffraction upon such masses.

(*b.*) "The glow may be due partly to diffraction, and partly to dispersion and refraction, perhaps the latter combined with absorption.

(*c.*) "The glow may be due to combinations of two or more of the above-named conditions, assisted perhaps by the gases of volcanic eruptions, or by unknown elements.

(*d.*) "The glow is the result of the united action of causes tending to produce iridescent halos, coronal colours, and twilight tints simultaneously."

The writer winds up as follows:—

"Assuming that the coloured tracts seen near the sun prior to 1883 were what are here called coronal, and were not the true sun-glow; also assuming that the

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[*] The most important of M. Dufour's remarks is the last sentence, as it coincides with the explanation we have already given of the difference in the quality of the haze observed nearer the eruption of Krakatoa, as in the Indian Ocean by the *Barbarossa*, *Simla*, *Charlotte*, and *British Empire*, in which case the entire air seems to have been filled with haze, and its aspect as a lofty semi-transparent layer in the higher latitudes.

[†] 'American Meteorological Journal,' vol. ii. (1886), p. 551.

[‡] The glow so-called by Professor Stone mainly refers to the coronal appendage seen round the sun during the day time. The twilight tints are considered as only secondary and subordinate.

[§] This refers to certain halos, or segments of halos, seen by Professor Stone during the winter, and by him connected with the corona and twilight glow.

changes of intensity of the sun-glow from day to day are not entirely due to changes in the transparency of the lower atmosphere, or to reflection from vapours, or haze, in the lower air, then I incline to the hypothesis that volcanic dust is largely concerned in the production of the glow, but that its effect is combined with some peculiarity of precipitation of moisture. And perhaps the most plausible theory connecting the action of dust with precipitation, that is, in a causal relation and not as contemporaneous merely, is that moisture condenses upon the dust, is in turn melted wholly or in part by the heat of the sun, often freezes again in irregular or globular form, thus no longer acting like ice crystals to produce distinct halos, but producing a complex result combining diffractive effects with several other optical effects."

Mr. Verbeek, after referring to the various evidence in favour of the connection between the optical effects seen after the eruption, and the materials ejected from Krakatoa on August 27th, expresses himself strongly against the theory that they were due to dust alone. He assumes that the quantity of fine dust thrown up into the higher regions did not exceed 1 cubic kilometre, and this, if spread over the earth, would amount to a layer of only ·002 mm. in thickness. He continues :*—

> Il n'est, donc, pas probable qu'une couche si excessivement mince de poussière ait été la cause principale des lueurs crépusculaires, que nous sommes alors bien obligés d'attribuer aux grandes masses de vapeur d'eau rejetées par le Krakatau et dont la quantité échappe, malheureusement, à tout calcul. Cette vapeur d'eau, qui formait la majeure partie de notre "nuage volcanique," occasionna après avoir été condensée et congelée dans les hautes et froides couches de l'atmosphère, les couchers de soleil d'une magnificence exceptionnelle; quant aux particules de cendre qui flottaient encore dans l'air, le rôle accessoire qu'elles ont pu jouer a été double : d'abord, elles ont pu augmenter l'intensité du phénomène, et, en second lieu, elles ont servi de centres de condensation pour la vapeur. La cause proprement dite des lueurs rouges était donc vraisemblablement la même que celle de la teinte rouge ordinaire du soir, et leur intensité particulière était une simple conséquence de l'énorme quantité de vapeur d'eau répandue dans les hautes régions de l'atmosphère à la suite de l'éruption du Krakatau.

Amongst others who uphold the volcanic theory of the origin of the glows and other phenomena, we may mention the following :—

(1.) H. Parker, Ceylon. 'Ceylon Observer,' September 20th. Letter dated Hambantota, March 18th, 1884.
(2.) L. Hargrave, Sydney. MS. letter dated May 10th, 1884.
(3.) W. J. Harrison. 'Knowledge,' December 21st, 1884.
(4.) N. R. Pogson, Madras.
(5.) W. R. Manley (Ongole). 'Nature,' vol. xxviii., October 11th.
(6.) J. Macaulay. 'Nature,' vol. xxix., p. 176.
(7.) Professor Forel, Morges. 'Archives des Sciences Physiques et Naturelles,' t. xiii., p. 465.

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* 'Krakatau,' p. 157.

(8.) M. G. Tissandier, France. "Sur la cause des lumières crépusculaires," 'Comptes Rendus,' vol. xcviii., February 4th.
(9.) C. L. Wragge, Adelaide. 'English Mechanic,' December 12th, 1884.
(10.) M. Perrotin. 'L'Année Scientique,' 1885, p. 46.

List of Authorities quoted in this Section.

E. Douglas Archibald.

PART IV., SECTION VII.

General Analysis of the Connection between the unusual Meteorological Phenomena of 1883–6, and the Eruptions of Krakatoa in May and August, 1883.

By Mr. E. Douglas Archibald.

We now proceed to discuss the main objections which have been put forward by various critics to the hypothesis to which a careful review of the evidence has led us, viz.: That all the unusual optical phenomena which appeared generally after the eruption of Krakatoa on August 26th and 27th, and continued thenceforward (in part) up to the middle of 1886, had their origin in the material ejected from that volcano during its eruption on the above dates.

Apart from the subordinate question of their being due to dust alone, vapour alone, or a combination of both, the main objections to the volcanic hypothesis appear to be the following:—

(A) The supposed abnormal rapidity with which the twilight glows, coloured suns, and cloud-haze were propagated round the world from the neighbourhood of Java, and their subsequent more leisurely spread in latitudes N. and S.

(B) The amount of material, especially if dust alone, required to spread nearly all over the world, and yet be of sufficient density and volume to produce the effects which were witnessed.

(C) The difficulty of accounting for the suspension of the material for so long a period as two, or two and a half years.

(D) The fact that volcanic eruptions are not invariably accompanied by similar effects.

(E) The fact that unusual twilight glows were reported as having occurred sporadically in the earlier months of 1883, and before the grand eruption of Krakatoa in August.

(A).

Of these objections, the first is met mainly by the facts detailed regarding the velocity of the so-called "smoke-stream" round the world westwards from Krakatoa, as traced by the successive first appearances of the twilight-glows and associated phenomena, during the last three days of August and the first part of September, 1883.

In Section III., p. 312, in which this is dealt with, we find irresistible evidence of the spread of the material from the neighbourhood of Krakatoa, mainly in a westerly direction. For the Indian Ocean and during the first two or three days, the velocities, as deduced from the successive appearances of the blue and green suns, present considerable divergences; but these are satisfactorily accounted for by the fact that several explosions of Krakatoa occurred between 2 p.m. of August 26th and 10 a.m. of August 27th, and that for some time previous to the former date, especially from August 22nd to 25th, all three craters of Krakatoa were more or less in constant eruption, so that while the smoke-columns arising from the first of these were probably of sufficient volume to affect nearer localities, it was only the later and more violent explosions, whose effects were transmitted right round the Equator.

The main points brought out by this investigation are—

(1.) The general transmission of the appearance of blue and green suns westward from the neighbourhood of Krakatoa, as shown by the successive dates on which they were seen in different longitudes.

(2.) The similar transmission of the after-glows and haze.

(3.) The generally fair agreement of the velocities of transmission of the several phenomena to different places.

(4.) The agreement between the average value, 70 miles per hour, for the coloured sun during the first revolution of the smoke-stream, and 72 miles per hour for that of the twilight-glows, from the most accurate data in each case.

(5.) The continued transmission of the main stream for at least a second equatorial revolution of the globe, with a proportionate spread in latitude.

(6.) An exceptional transmission in a N.N.E. direction towards Japan at about 39 miles per hour.

With the exception of this last anomaly, and a transmission towards the Cape, which appears to have been an offshoot from the main westerly stream, the transmission seems to have been on the whole remarkably regular; the exceptional values occurring for the most part in the Indian Ocean, where any error in the exact date of the particular eruption from which the material issued would more affect the values, and where probably a good deal of the material was due to the minor activity, anterior to the final outburst.

The necessary postulate to explain this remarkable transmission is evidently a current near the Equator, from east to west, at an altitude far exceeding the ordinary upper current systems. We shall subsequently discuss this question more fully, but it may be here stated *in limine*, that there is no *à priori* objection to such a current, and that a velocity such as that demanded is not uncommon at lofty altitudes in the atmosphere.

Mr. VERBEEK * has similarly worked out the velocity of the smoke stream from the times at which the optical phenomena made their appearance at Trinidad,

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* 'Krakatau,' p. 151.

Fanning Island, Strong Island, Madras, &c.; and has arrived at the conclusion that, both on its first and on its second journey, the stream had an average velocity of 1,725 nautical miles per day, or 82·9 statute miles per hour. He takes for his starting point, however, August 27th, 10 a.m., instead of August 26th, 2 p.m., which would reduce the velocity to 78·2 miles per hour. The former epoch is probably more nearly correct for the longer transmissions than is the latter. The calculation agrees substantially with that given by the Hon. ROLLO RUSSELL, in Section III., p. 337. The complete period of revolution round the globe, according to this, would be 12½ days.

The exceptional stream which made its way to Japan, and caused the copper-coloured sun, and other effects witnessed at Tokio, Nikko, and Yokohama, appears, like the grand westerly current, to have been both narrow and straight; the phenomena appearing progressively along an almost direct line from Krakatoa to Japan, as follows:—

		Approximate time of appearance.
Labuan Island..	5° 16′ N. 115° 15′ E.	August 27th, 6 p.m.
Fisher Island ..	23° 32′ N. 119° 33′ E.	August 29th, 6 p.m.
Tokio ..	35° 40′ N. 139° 45′ E.	August 29th, 6 p.m.
Japan (generally)	..	August 30th, noon.

From which we get the following rates of progression, assuming the material to have been ejected from Krakatoa on August 26th, at 2 p.m., and to have proceeded thence in a straight line to each place respectively.

		Miles per hour.
Krakatoa to Labuan Island		41
,,	Fisher Island..	32·1
,,	Tokio ..	46·8
,,	Japan (generally)	37·6
	Mean ..	39·3[*]

The individual rates, as well as their mean, are here considerably lower than (not much more than half of) those for the motion of the material which was carried due west. At the same time, the fact that the material was carried with such

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[*] Professor J. KIESSLING, of Hamburg, similarly arrives at a maximum value for this current of 20 metres per second, or 44·7 miles per hour. 'Die Bewegung des Krakatau Rauches' in September, 1883, 'Sitzungsberichte der Kön. Preuss. Akadamie der Wissenschaften zu Berlin,' vol. xxx., 1886.

comparative rapidity as far as Japan, shows it to have been borne thither by a current of some considerable elevation.

A somewhat similar projection of the heavier dust appears to have taken place in a S.S.E. direction towards Australia, off the coast of which the *Meda*, on the night of August 30th, experienced a fall of dust at a distance of about 1,150 English miles from Krakatoa.

Since, during the month of August, the prevailing surface wind in the Java Sea is the south-east or north-east monsoon, and the falls of the heavier ashes appear to have mainly followed these directions over a wide area of the Indian Ocean, it seems reasonable to conclude that the transmissions towards Japan on the one hand, and towards Australia on the other, were due to a portion of the material having dropped or spread into the upper S.W. and N.W. anti-trades, which are known by observation to exist above the ordinary surface N.E. and S.E. trade winds of these latitudes.

The fact that these exceptional transmissions took place only to a limited extent, however, as well as the much greater velocity and mass of the main stream which made its way right round the Equator, shows that while part of the ejecta was, as it were, entrapped by the ordinary wind systems which prevail at lower elevations and up to the level of the highest clouds, a large quantity of the material was probably projected to a level at which we have no means of ascertaining by the aid of clouds what are the motions of the air, since aqueous vapour does not exist in sufficient quantity to form them, and at which the prevailing motion is apparently a powerful current from the east right round the Equator.

All the leading facts regarding the earlier distribution of the optical phenomena tally with such an hypothesis.

Also there does not seem to be any *à priori* objection to the existence of such a current, unless the phenomena demanded its presence in all parts of the world, which would involve a violation of the law of continuity.*

Now, the evidence from the section in which the geographical distribution of the optical phenomena is dealt with, shows, on the contrary, that while in the equatorial zone the manner in which the first appearances succeeded one another, demands a due westerly current of considerable velocity, that in which they afterwards spread into higher latitudes in the northern hemisphere, shows a north-easterly trend,† the reputed movement of the haze wisps being likewise in the same direction. Moreover, as if to show that between two such currents, from the east near the Equator, and from the west in high latitudes, an area of no east-west motion, or calm belt, occurs, as in the trades at the surface, we find in October, when the phenomena had reached

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* Except in the event of the motion of the lower air preponderating in the reverse direction all over the globe, which is not the case.

† The approach of the glow phenomena, both towards Europe and towards America, seems to have been from the south-west.

30° N., fewer accounts of their reaching new places than before or after that date; and they appear, during that month, to have spread only slightly in latitude.

With the exception, therefore, of the necessity of explaining the rapid transmission of the main body of the ejecta westwards by a constant easterly current (at least in August and September) at an elevation of over 70,000 feet near the Equator, of which we have no previous observational proof,[*] there does not appear to be any positive objection to the volcanic hypothesis, arising from the facts ascertained regarding the distribution.

The fact that the heavier dust mainly fell on ships to the west of Krakatoa, tallies with the same postulate, since most of it must have been originally projected to the same height as the finer material which remained floating at the higher limits; but, yielding more readily to gravitation, it fell through the ordinary upper currents into the lower trades.

The question of the direction and velocity of the stream which carried the main mass of the ejecta westwards is so important that, although it has been already briefly discussed in Section III., p. 312, we shall here enter into a more detailed *résumé* of the initial spread of the optical phenomenon and its relation to what is known, by theory and by observation, of the general motions of the upper atmosphere near the Equator.

On referring to the facts discussed in Section III. relating to the general geographical distribution of the coloured appearances of the sun, and the unusual glows at twilight which were observed on the edges, or in the thinner parts, of the main stream or succession of eruption clouds, we find the following mean limits for their several extensions along the main east to west current:—

Circuit I.

	Indian Ocean.	Atlantic Ocean.	South America.	Pacific Ocean.
		° ′		° ′
Twilight glows	..	13 30 N. 16 50 S.	11° N. 33° S.	22 0 N. 16 0 S.
Coloured suns	10° N. 5° to 20° S.	10 40 N. 14 0 S.	.. ..	10 19 N. 13 17 S.

Circuit II.

Twilight glows, generally from the Equator to from 20° to 30° N.
" " " from 30° to 40° S.
Blue and green suns " " from 15° to 19° N.
(Southern limit unknown.)

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[*] Except Mr. Abercromby's itinerary observations referred to further on.

If we analyse these we shall find that on their first circuit the mean latitude of the centre of the band of the twilight glows was 6° 10′ S. (the latitude of Krakatoa being 6° 9′ S.), and their mean extension north and south of this position was ± $15\frac{1}{2}$°.

For the coloured suns, the mean latitude of the centre of the band was 5° 26′ S., and the mean extension of the phenomenon north and south of this was ± 10° 49′.

The latter, therefore, was more restricted than, but very similar in position and extension to, the former.

During the second circuit the limits are not so determinate; but, omitting extremes, we may take the twilight-glow band to have had its central line about 6° S., and to have extended north and south of this for about ± 30°.

Up to October 5th this rate of expansion for the stream seems to have been fairly maintained, but after this epoch we find a distinct retardation in the latitudinal spread of the main body of the haze, and thenceforward its course is doubtful. Apparently, it reached lat. 35° by the end of October; then, in November, a sudden rush took place, which, by the end of the same month, caused the phenomena to be seen over the major part of North America and Europe, up to lat. 60°. A change in the direction of motion appears to have taken place in October, after which the material seems to have been wafted along by a different set of currents. Whether the material spread by the action of any other laws* than those which usually regulate the motion of the air in which it floated, and at what time it ceased to move from east to west, it is difficult to say, but the facts negatively favour the view that by the time it reached latitude 30° it no longer possessed that due east to west direction by which at first its general motion within the tropics was so markedly characterised. Beyond this limit the facts relating to the march of the glows over North America, Europe, and Northern Asia show that the current which brought the glow-causing material, whether simply the south-west anti-trade or a current analogous to it at a higher level, carried it more from west to east than from east to west. There is, indeed, a remarkable absence of any succession of appearances from east to west beyond latitude 30° N., and a general impression conveyed by the facts that, while the material was crossing this limit it was simply spreading north and south, and afterwards turned round so as to move, if anything, from south-west to north-east.† If this was the case, its general motion beyond the tropics was similar to what that of the usually so-called higher parts of the atmosphere should be, according to the modern theory of atmospheric circulation.

The accompanying diagram represents the general scheme of atmospheric circulation, according both to theory and to observation, and is taken from Dr. SPRUNG'S 'Lehrbuch der Meteorologie' (Hamburg, 1885). The central portion

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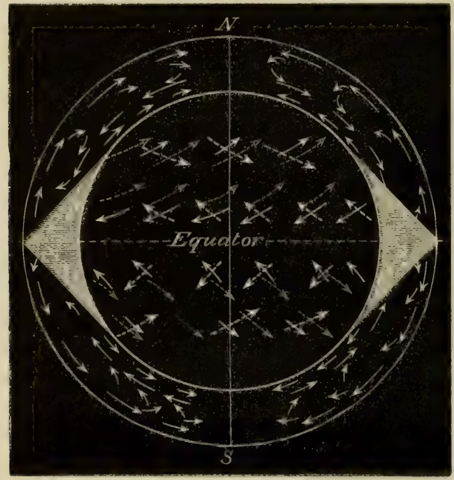
* Such as electrical repulsion.

† *E.g.*, the apparent motion of the wisps of cloud-haze observed by Professor RICCÒ and Mr. RUSSELL.

represents the motions in the different layers in plan, and the outer ring, in meridional section.

It will be observed that over the Equator, and for some considerable space on each side, there is an hiatus as regards the current in the higher regions; and, indeed, the formula for the easterly component of velocity, derived by Ferrel from the general hydro-dynamical equations for the atmospheric motion, fails for this space.



Lower currents ——. *Middle currents* — — —. *Upper currents* - - -.

It is as follows :—

$$V_E = \frac{\frac{g}{K}\frac{d \log P}{dn} - h\frac{d \log K}{dn} - \frac{d V_N}{dt}}{2\,\omega \sin \phi}\ \text{Sin}^2\psi$$

where—

V_E is the eastward component of velocity,
K the pressure constant depending on temperature and humidity,
P the barometric pressure at sea level,
n distance from the North Pole,
h the height above the surface,
V_N the meridional component of velocity,
ϕ the latitude,
ψ the inclination of the wind to the isobar,
ω the angular velocity of terrestrial rotation.

Since sin ϕ occurs in the denominator of this equation, V_E becomes infinite near the Equator, and the formula impracticable.

Both Dr. SPRUNG and Professor FERREL, in fact, stop all their quantitative and qualitative evaluations of the motions of the upper atmosphere between 15° north and 15° south of the Equator, leaving a space *more than a quarter of the entire surface of the earth* theoretically unprovided with an upper current system. We can, however, from other considerations, arrive at some notions of what the direction of motion of the upper air over this region should be.

The general theory of atmospheric circulation, according to FERREL, SPRUNG, and others, gives us the following equations for the relation between the barometric gradient towards the pole, and towards the east, and the eastward and polar components of the general motions of the air (for the northern atmosphere)—

$$\frac{\mu}{\rho} G_N = 2 V_E \omega \sin\phi + \frac{V_E^2 \sin\phi}{r} + \frac{dV_N}{dt} + F_N \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

$$\frac{\mu}{\rho} G_E = \frac{dV_E}{dt} - 2\omega V_N \sin\phi - \frac{V_E V_N \sin\phi}{r} + F_E \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where G_N ,G_E are the barometric gradients at sea level respectively in a northerly and easterly direction.

V_N, V_E, the corresponding velocities of the wind.
ω, the angular velocity of the earth's rotation.
ϕ, the latitude of the place.
r, the radius of the circle of latitude.
F_N, F_E, the terms expressing the friction which retards the velocity in a north and east direction respectively.
μ,* a constant by which the gradient is converted into force units.
ρ, the density of the air.

Now, in the neighbourhood of the Equator sin ϕ becomes very small, and finally vanishes on the Equator.

Also, $\frac{d\,V_N}{dt}$ and $\frac{d\,V_E}{dt}$ may be neglected where there is an absence of *irregularity* in the motion. Moreover, when we are dealing with the motion of the air at a great height, such as 100,000 feet, F_N and F_E become very small. Finally, the term $\frac{V_E^2 \sin\phi}{r}$, which arises from the geodetic curvature of the circle of latitude, becomes very small near the Equator. Over the equator, therefore, corresponding to a large value of either V_E or V_N, there might be no sensible gradient either towards the pole or eastwards. Also, for any *continuous* motion *along* the Equator, G_E must $= 0$, so

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* According to Guldberg and Mohn: $\mu = g_{_{45}} \times {\cdot}000012237$.

that the second equation need not come into consideration at all in this case. If we desire to know which of the following five possible states is dominant in the upper regions of the atmosphere over the Equator viz.—

(1) A motion from E. to W.,
(2) A motion from W. to E.,
(3) A motion from N. to S.,
(4) A motion from S. to N.,
(5) No motion at all,

we can arrive at some preliminary notion from theory alone, for since the Equator is approximately an axis of thermal as well as rotational symmetry, any motion of the air towards or from it, due to either, or both, solar heat or terrestrial rotation, should tend to occur symmetrically (*i.e.*, in opposite directions and equivalently) on each side of it. Meridional components should, therefore, vanish on the Equator, and have only small values in its neighbourhood. E. or W. components, on the other hand, might have considerable but nearly equal values on each side of it.

As a matter of observation, we know that, with the exception of the Indian area and a portion of the West African and American areas in the summer, the trade winds blow regularly on each side towards the Equator, and thus the air above can only *begin* to stream polewards from a central region of *no meridional motion,* on the north side towards the north pole, and on the south side towards the south pole.

We know also that not only the sea level gradients near the Equator are small, but that up to 13,000 feet there is little change, and above this height there is nothing to show that the gradients towards the poles would be of any magnitude for at least 15° on each side of the Equator.

This agrees with what we have just shown, viz., that at a high elevation in the neighbourhood of the Equator, the first general equation reduces to the form

$$\frac{\mu}{\rho} G_N = 2 V_E \omega \sin \phi$$

which is itself a very small quantity.

The mean barometric readings and gradients at sea level, and at a height of 13,000 feet for the tropical zone, as calculated by Dr. SPRUNG, are as follows * :—

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* 'Lehrbuch der Meteorologie,' Hamburg, 1885, from data by Professor FERREL. 'Meteorological Researches,' Vol. I.

Mean Barometric Pressures in Inches.*

Latitude.	Sea Level.	Gradient.	13,123 feet.	Gradient.
° 20 N.	29,890		18,504	
		+ ·051		− ·028
10	29,839		18,532	
		− ·004		− ·011
0	29,843		18,543	
		− ·043		− ·004
10 S.	29,886		18,547	
		− ·103		± ·0
20	29,989		18,547	

+ gradient from N. to S. — from S. to N.

It will be noticed that the gradients near the Equator are small each way, and that, though at 13,000 feet the gradients towards the poles have relatively increased by the following amounts :—

$$\begin{array}{l}\left.\begin{array}{r}\text{Latitude } 20^\circ \text{ to } 10^\circ \text{ N., } \cdot079 \\ 10^\circ \text{ ,, } \quad 0^\circ \qquad \cdot007\end{array}\right\}\text{S. to N.} \\ \left.\begin{array}{r}0^\circ \text{ ,, } 10^\circ \text{ S., } \cdot039 \\ 10^\circ \text{ ,, } \quad 20^\circ \qquad \cdot103\end{array}\right\}\text{N. to S.}\end{array}$$

The increase within 10° N. and 10° S. is very small, and could never become absolutely large even at the higher levels.

We may, therefore, regard $\pm V_N$ as virtually non-existent near the Equator.

With reference to (1) (2) or (5), it must be observed that—

(*a.*) While the meridional components of the trade-winds are obliterated by their quasi-junction near the region of the doldrums or thermal Equator, there is nothing to counteract their E. to W. components, and since, by the conditions of continuity, we must assume that they rise either as a common convection current, or else through an upward deflection of their stream-lines by a medial wedge of doldrums, the air up to a considerable elevation over the Equator should retain this combined E. to W. motion unchecked.

The general equations do not help us *positively* here, since, owing to the vanishing of practically all the terms at a high elevation, the expressions for V_E become unintelligible or indeterminate. The E. to W. velocity could, however, only be

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* From the original figures in millimetres.

stopped by friction, which is very small at high elevations; and it would, moreover, be continually kept up, notwithstanding the ultimate overflow of the air towards the poles, by the constant accessions of similarly moving air from the rising trades below.

(*b.*) If this E. to W. motion were once established in the upper atmosphere near the Equator, the air would tend *to continue to move in that direction*, owing to the fact that, apart from any decided poleward motion due to overflow, which we have shown cannot occur except at some distance from the Equator, the inertia curve in which the air would tend to move would in this case coincide with its initial direction.

For the radius of the inertia curve in any latitude ϕ

$$= \frac{V}{2\,\omega \sin \phi}\,{}^{*}$$

At the Equator, therefore, the radius $= \infty$, and the curve becomes a great circle for initial motion in any azimuth. For motion continually reproduced from E. to W. it coincides with the Equator itself.

(*c.*) In the absence of any other positive cause, an eastward motion can only arise in consequence of the deflection force due to terrestrial rotation acting upon a N. or S. meridional component of velocity. Both of these, as we have shown, are very small in the neighbourhood of the Equator.

Unless, therefore, the air is affected by any powerful external influence, causing it to move towards the poles, it will, at the higher levels, where there is little or no friction, tend to move continually from east to west with considerable velocity along the isobars, in spite of a small gradient; since that component of the gradient which usually counteracts the tendency of the air to fly round in the more rapidly curving inertia curve elsewhere, is here insensible.

Further away from the Equator, where the gradient towards the poles becomes more marked, and the radius of the inertia curve smaller, it will gradually turn round through E., S.E., S. to S.W., the last being the known direction of the cirrus clouds at the borders of the trade zones, while the S.E. direction is found nearer the Equator, as may be gathered both from the direction of the middle currents in the diagram on p. 432, and from the following remark by Dr. SPRUNG :—

"Da sich aber hierbei die aequatoriale Komponente der Bewegung allmälig in eine polwärts gerichtete verwandelt so muss z. B. über dem Nordost-passat an

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[*] The following table, given by Dr. SPRUNG ('Lehrbuch der Meteorologie,' p. 27), shows the change in the value of the radius of the inertia-curve with the latitude for a given value of V.

V	Lat.	0°	2½°	5°	10°	20°	60°
44½		∞	1886	943	474	240	94
Miles per hour.			miles.				

der Erdoberfläche ein Sudost Wind in der Höhe sich entwickeln: ein Resultat welches durch die Erfahrung bestätigt wird." *

Mr. ABERCROMBY's itinerary observations in the Atlantic and Indian Oceans, the results of which, in as far as they bear on this important question, are given in 'Nature' (vol. xxxvi., p. 85), confirm the view that the general dextrorsal motion in the Northern, and sinistrorsal motion in the Southern, Hemisphere of the upper currents relatively to the lower currents, combine in a general due east to west motion over the neighbourhood of the Equator, at least as far as the level of the highest visible cirrus is concerned.

Regarding the question of the probable velocity of this east to west current over the Equator, we know hardly anything beyond the evidence afforded by the present "smoke stream." Observations of cirrus clouds in higher latitudes, certainly show velocities considerably exceeding 80 miles an hour,† but these are in connection with large depressions near the poles, and are not constant.

The velocity in the present case could certainly not be attributed in any sensible degree to the westward lag of material ejected from the earth's surface, since, even at a height of 120,000 feet, such lag would at the most amount to only 6 miles an hour, assuming that none of it was lost by friction during ascent.

That the velocity *might*, however, be considerable at a high elevation near the Equator, in spite of a small gradient, is plain both from what was said about the general equations for the gradient, as well as from the following complete equation for the barometric gradient in terms of the velocity, viz. :—

$$G = \frac{1076{\cdot}4\,(2\,\omega\sin\phi + v\cos i)\,v}{\cos i\,(1 + {\cdot}004\,t)}\,\frac{P}{P^1},$$

where i = inclination to the direction of the gradient,

t = temperature in degrees centigrade, and P P^1 are the barometric pressures at the given height and at the earth's surface respectively, the other symbols having their usual signification.

At the Equator—

$$2\,\omega\sin\phi = 0$$
$$t \text{ is large ;}$$

while, at a great height above the surface, the friction being inappreciable, $\cos i = 1$ and the ratio $\frac{P}{P^1}$ becomes very small.

All these circumstances combine to allow a large value of v to coexist with a small one of G, at great heights in the neighbourhood of the Equator.

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* 'Lehrbuch,' p. 203.

† 120 miles and more, according to CLEMENT LEY's 'Laws of the Winds,' p. 163.

We may, therefore, conclude that both theory and observation rather favour than otherwise the existence of a rapid and *constant* current from east to west for some degrees on each side of the Equator in the loftiest regions of the atmosphere, such as is demanded, if not shown to exist, by the succession of optical appearances after the August eruption of Krakatoa in 1883 traced in this report.

(B).

The second objection (insufficiency of ejecta) is one with which it is impossible to deal from a purely theoretical point of view.

From Mr. VERBEEK's official report to the Dutch Government on the disaster,* we gather that he calculates the total quantity of solid material which was ejected from Krakatoa in the grand eruptions of August 26th and 27th to be 18 cubic kilometres (4·3 cubic miles). Of these no less than 12 cubic kilometres (2·86 cubic miles) lay within a distance of 15 kilometres (9·3 English miles) drawn round Krakatoa, the thickness diminishing from 30 metres (98 feet) close to Krakatoa to from 1 to 1½ metres (3 to 5 feet) at about 20 kilometres (12·4 miles) distance. From 22½ to 40 kilometres (13·9 to 24·8 miles), the average thickness of the ashes amounted to 0·3 metre (1 foot), then to 50 kilometres (31 miles) 0·2 metre (8 inches). At a still greater distance from Krakatoa, the thickness speedily diminished to 2, 1, and ½ a centimetre (·8 to ·2 inch). This calculation, however, as Mr. VERBEEK admits, may be too low; and as he estimated the area over which the finer dust fell † to be no less than 750,000 square kilometres (*i.e.*, almost as large an area as Sweden and Norway together), it is evident that the calculation can be only approximate, and that a large quantity of the material which fell may have escaped calculation, owing to its being ejected to a greater height than usual, and carried rapidly away over parts of the Indian Ocean, where observations could not readily be made.

Several circumstances combine to favour this view :—

(1.) The height to which the smoke-column on the 26th of August was seen to ascend from the *Medea*, viz., from 17 to 21 miles; and as this was before the greater explosions on August 27th, the height attained by the finer as well as coarser materials, may subsequently have considerably exceeded this value.‡

(2.) The unparalleled distance to which the sound of the explosions (especially those on the 27th) was propagated, reaching on the one side Alice Springs in Australia, 2,233 English miles from Krakatoa, and, on the other, Rodriguez, nearly 3,000 English miles distant, and embracing a total area of nearly one-thirteenth

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* 'Krakatau,' page 140.

† This estimate entirely omits what fell on ships traversing the Indian Ocean, as will be seen subsequently.

‡ As we have already noticed in Section IV., p. 340, Mr. VERBEEK estimates the height to which in the August eruption some of the coarser fragments were ejected to have been 164,000 feet, or about 30 miles.

of the entire surface of the globe, the most regular portion of the area forming a circle of 30° in radius.

In the eruption of Tomboro in 1815, the area over which the sounds were audible embraced a circle having a radius equal to 15°, or an area less than a quarter of that over which those which emanated from Krakatoa on the present occasion were heard.

It thus appears, according to the law of dissipation of sonorous energy, that the energy of the Krakatoa eruption of August 26th and 27th was probably at least four times as great as that of Tomboro. If this was the case, it seems curious that the amount of solid matter ejected, estimated by what fell, as well as by the duration of the darkness which supervened, should, in the eruption of Tomboro, have appeared to be so much greater than in the case of Krakatoa.

Thus, while in the case of Krakatoa the darkness did not, as a rule, exceed 24 hours, it is said in that of Tomboro, to have lasted three days consecutively at Madura ; and while the total amount which fell in the former case is estimated by Mr. VERBEEK at only 18 cubic kilometres (4·3 cubic miles), he estimates the amount which was thrown out by Tomboro, on more correct data than those originally employed by JUNGHUHN, at no less than 120 cubic kilometres (28·6 cubic miles). There seems, however, to be some considerable doubt as to the correctness of some of the evidence regarding both the duration of the darkness and the amount of solid ejecta in the case of Tomboro, the former being solely inferred from a single observation at Madura, and the latter from observations at a few places to the west only of Tomboro. Also, since it appears that the ashes from Tomboro, like those from Krakatoa, were carried mainly in a westerly direction, places to the east experiencing much lighter falls, and as land extends due west of Tomboro to a much greater extent than in the case of Krakatoa, it is possible that the discrepancy between the two cases may be due in some measure to these circumstances.

Still, in any case, it seems that in proportion to its extreme violence, a much smaller quantity of matter fell round the immediate vicinity of Krakatoa than round Tomboro, and we are thus led to conclude either that the eruption of Krakatoa was more gaseous, or that the materials were projected to so immense an elevation, and were for the most part so pulverised into the minutest dust, that a smaller quantity than usual remained in such a form as to yield immediately to the force of gravitation and fall in the vicinity of the volcano.

(3.) The rapid dispersion of the finer ashes over a large sea area, chiefly to the west of Krakatoa ; corresponding in this respect with the heavier ashes, which, according to Mr. VERBEEK, reached Singapore and Benkalis, 522 and 565 English miles respectively from Krakatoa to the north-west, and Keeling Islands 733 English miles distant to the south-west ; while to the east they reached only the western portions of Preanger and Krawang in Java, not much more than 120 English miles from the volcano, their density in like manner falling off much more rapidly towards the east than towards the west.

(4.) The remarkable series of air-waves (apart from actual detonations), the course of which has been traced round the world by General STRACHEY in Part II., p. 57 of this report, and which show that one of the explosions, that of 10 hrs. 2 mins.* on August 27th, was of extraordinary and exceptional violence.†

Some persons, including Dr. JULIUS HANN, have endeavoured to estimate the amount of dust projected, by supposing the whole mass of the volcano to have been blown into the air. According to this hypothesis, and making certain allowances, he estimates the thickness of the stratum produced, if spread over the whole world, at ·0004 inch; but while the assumption on which this deduction is based is a serious over-estimate in one direction (only a part of the real peak having disappeared, according to Mr. VERBEEK) it is equally an under-estimate in another, no account having been taken by Dr. HANN of the possibility of a large amount of the material having been derived from beneath the volcano. That this was most probably the case may be inferred, not only on theoretical grounds, but also from the fact mentioned by Mr. VERBEEK, that among the ejecta of the volcano were found fragments of the underlying sedimentary rocks.

The amount of dust assumed by Mr. VERBEEK, in his 'Krakatau,' to have been ejected into, or to have remained floating in, the higher atmospheric regions, is less than 1 cubic kilometre (0·24 cubic mile), out of the total 18 cubic kilometres (4·3 cubic miles); but we have just shown that there are several reasons for thinking this to be a considerable under-estimate, and in favour of one of these, viz., that a large portion of the material was triturated by the unusual force of the eruption into the very finest dust, may be mentioned the remarkably distended and vesiculated character of such of the dust as has fallen and been examined.

We shall not, therefore, be over the mark if we tentatively assume that 4 cubic kilometres (1 cubic mile) out of, or rather besides, the total 18 cubic kilometres of solid matter estimated by Mr. VERBEEK, was expelled from the volcano in the form of fine dust into the higher atmospheric regions during its eruptions of August 26th and 27th.

Let us now see how thick a stratum this quantity would produce when spread out uniformly at a height of 70,000 feet over the entire globe. If it were reduced to the form of a solid continuous layer, this quantity would, in such a case, = ·0003 inch in thickness, or a trifle less than that inferred by Dr. HANN on a different assumption to be a probable mean value. This quantity certainly seems to be rather microscopic, and it appears, *primâ facie*, quite incapable of producing the

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* VERBEEK's time; 9 hrs. 58 mins. following Gen. STRACHEY.

† It is possible, of course, that similar waves may have been caused by former eruptions, but have escaped unnoticed, owing to the absence until recently of any large number of self-recording barometers, by which alone their existence could have been detected.

transmissive or reflective effects which were witnessed. Before, however, we call in the aid of any concomitants, or assume a larger quantity of material to have been ejected in the form of very fine dust, let us endeavour to arrive at some idea of the possible effects of such a quantity of dust alone.

From FARADAY'S[*] researches on the colour of gold and other metals when diffused in liquids in most minute particles, we know that gold leaf can be obtained of $\frac{1}{1600}$th the thickness of the above stratum, or less than $\frac{1}{50}$th of the length of a wave of light, and still reflect a golden and transmit a green colour. Also gold particles of ultra-microscopic fineness, can be obtained in solutions which transmit beautiful blue and ruby-coloured light, and can be diluted with 750,600 times their volume of water without diminishing the tint.

In the present case, the solid particles certainly had not the same powerful optical properties as gold, but since they were mostly thin bubble plates of volcanic glass, they would tend to preserve reflective properties longer than ordinary terrestrial dust, even when scattered through a considerable vertical space.

Let us take, as an analogous case, a hypothetical cirrus cloud in the tropics, at an elevation of 15,000 feet, and 20 feet in vertical thickness.

Now, from Professor S. A. HILL'S 'Meteorology of the North-west Provinces of India,'[†] we find the mean annual tension of aqueous vapour at this elevation, on the slopes of the Himalaya, to be 0·18 inch, the mean annual temperature at the same elevation being about 32° Fahrenheit. If we assume the vapour tension for the cirrus cloud to be 0·30 inch, which is considerably above the average at that level, we shall find the thickness of the water stratum corresponding to this cloud = ·0018 inch, which is about six times that of the dust-stratum on the foregoing assumptions. The number of particles of vapour (supposed to be condensed) in the one case, and of dust in the other, contained in these vertical thicknesses, would be somewhat similar.

Thus Professor STOKES, P.R.S., from an observation which he made of an ordinary lunar corona, estimated the diameter of the vapour globules which caused it (assuming them to be spherical) to be ·0005 inch. There would thus be an average of 3½ of these (packed close together), in a vertical section of the hypothetical cirrus cloud. Taking the diameter of the particles composing the solid part of the cloud-haze in the present case (as deduced from the diameter of the corona in Section I. (E)) to be ·00006 inch, there would be 5 of such (assumed spherical) particles packed close together in a vertical section of the haze-stratum. If, as is probable, the particles were exceedingly thin pumiceous bubble plates, floating with their flat surfaces horizontal, there might have been a considerably larger number of them present, and their general optical effect much enhanced. It can scarcely be doubted that a cirrus cloud of the dimensions above assumed, would be capable of producing appreciable reflective and transmissive effects, and, therefore, it does not seem to be

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[*] 'Phil. Trans.,' 1857, p. 145.

[†] 'Indian Meteorological Memoirs,' vol. i.

absolutely impossible that such a dust layer alone, as long as it existed in a stratum of comparatively small vertical dimensions, might be capable of producing appreciable twilight effects, although nearly invisible during the day.

It must also be remembered, that at first the ejecta were, up to the end of September, principally confined to a belt within the tropics, the principal portion not extending generally beyond 15° north and 15° south of the latitude of Krakatoa.* It would thus be of at least double the density deduced above, and therefore be more efficient to produce the transmissive and obstructive, as well as lurid-reflective, effects which were witnessed in those regions.

The difficulty of conceiving how so small a quantity of solid matter alone, could have caused such widespread effects, has led many persons to reject the volcanic hypothesis altogether, and to adopt others in which, if dust be assumed to have been the principal agent, it was meteoric, or cosmical; and if aqueous vapour alone were concerned, it is assumed to have existed in a more copious quantity than usual in the upper atmospheric regions.

Both these are speculations with nothing to support them.

Two, more rational, views are prevalent, which we shall consider in turn :—

(1.) That the dust thrown up by the volcano was mingled with large quantities of aqueous vapour or with gases, also derived from the same sources, and that these gases condensing round the dust nuclei, after the manner shown by Mr. AITKEN, formed a sufficient quantity of cloud in the upper regions to account for the phenomena, both as regards intensity and universality.

(2.) That the particles of dust thrown up by the volcano acted as nuclei for the vapour already existing at the level it attained, to condense upon it in the form of minute ice spiculæ.

The only essential difference between these two views is the source of the vapour. Either, or a combination of both hypotheses, seems, *primâ facie*, possible; but there are positive objections to both, and several circumstances which go to show that if the particles of volcanic dust simply acted as nuclei for condensation, they yet possessed properties which caused the clouds thus formed, to exhibit physical characteristics, differing in many essential points from ordinary aqueous clouds, formed, as AITKEN would tell us they are, round ordinary dust nuclei.

In opposition to the notion that any very large quantity of aqueous vapour was ejected with the dust during the eruptions of August 26th and 27th, we have a remarkably general absence of accounts of rain falling during the eruption, it being mentioned only twice,† and, on the other hand, the ashes were in many cases so dry and hot that they burnt the skin of those exposed to them;‡ and, in other cases,

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* In longitude 157° W. it appears to have widened to 21° N., and sporadic observations occurred outside the above limits.

† 'Krakatau,' pp. 49, 53.

‡ 'Krakatau,' p. 53.

burnt holes in the sails of ships and in persons' clothes.* There was a rain of mud which fell chiefly in the adjacent districts of Sumatra and Java; but this was confined to a distance of 100 kilometres (62 miles) from the volcano,† and occurred only after the great explosion of 10 hrs. 2 mins. on August 27th, when, from the breaking up of the volcano, the eruption had become submarine. It also lasted only a short time, being succeeded by fresh falls of dry ashes.

The principal dynamic agent in effecting the ejection of the materials was probably steam; but it must be remembered that, in the first place, it would, under the diminished atmospheric pressure at the great height to which it suddenly attained, expand enormously, triturating into the very finest powder the lava within which a good deal of it was enclosed, and then, becoming rapidly cooled by the low temperature of the surrounding atmosphere, contract to the bulk of the water from which it was originally derived.

If, therefore, we suppose the steam to undergo these physical operations at an average height of 70,000 feet above the earth's surface, where the atmospheric pressure is about 1·34 inch, it would, first of all, tend to expand to about 34,000 times the volume of its original water, and afterwards freeze into ice spiculæ of about the same fraction of this bulk.

Assuming that the comminuted pumice was spread over something like the same volume as the steam when expanded, unless the vapour was greatly in excess of the solid matter, each particle of dust would be very little increased in bulk by the ice-coating it would receive from the surrounding highly attenuated vapour. Even if we accept the usual supposition, that of the cloud which hangs ordinarily over a volcano $\frac{999}{1000}$ths are composed of steam, the remaining $\frac{1}{1000}$th alone being made up of solid products, we should still arrive at the conclusion that, if such a cloud were suddenly exposed to a temperature below the freezing point of water, the ice resulting from the frozen vapour would barely double the existing bulk of solid matter.

Therefore, if the amount of dust alone, ejected from Krakatoa was insufficient to produce the optical phenomena in question, the condensation of the accompanying aqueous vapour does not seem to introduce any marked diminution of the difficulty.

Then, as regards the alternative hypothesis, viz.: that the dust thrown up into the upper regions would act as nuclei for the condensation of vapour which already existed there, it seems improbable that at altitudes of from 70,000 feet to 100,000 feet or more, any but an almost infinitesimal quantity of vapour does, or can continue to, exist. Professor Hill has found, by an application of Dr. Hann's formula,

$$\log p = \log P - \frac{h}{23{,}058},$$

(where p, P, h are the vapour tension, pressure, and height in feet at any elevation,)

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* 'Krakatau,' p. 74.

† *Ibid.*, p. 138.

that in the Himalayan zone the quantity of vapour ordinarily present in the air at 23,000 feet is only one-tenth of that at sea level.*

As the above formula is found to give larger values for p than those observed above 9,000 feet, we may assume that we shall not get a result *under* the mark if we suppose it to hold up to 70,000 feet. Taking the pressure at this height to be about 1·34 inch, we shall find $p = \cdot 00134$ inch (approximately), a quantity so small that each cubic foot of air would contain only 0·01 grain of water vapour. When we remember that at a height of about 7,000 feet in the Himalaya the air ordinarily contains as much as 3 grains of water vapour per cubic foot, we realise how small a quantity would be available at 70,000 feet.

Unless, then, some extraordinary intrusion of vapour unconnected with the eruption took place in the upper regions (of which no independent proof is forthcoming), it seems difficult to imagine how the mere presence of dust at such an altitude could collect vapour enough to form an aqueous cloud of any sensible thickness.

We must, therefore, abandon the idea that the haze was made up of vapour normally existing in the upper regions, and condensed round the dust particles.

Even if we suppose that the amount of vapour ejected by the volcano was enough for the purpose, either alone or with the dust, we are again confronted by two sets of difficulties—one arising from the principles of meteorology, and the other from the peculiar physical properties of the haze. A cloud, as we ordinarily understand the term, is always formed and maintained in a more or less ascending current. Directly the air begins to descend, or even to remain vertically stationary, the cloud tends to dissolve.† Even cirri are only formed where the humid air is pouring out from the centres of cyclones, and they disappear as the air which carries them descends into the neighbouring anti-cyclone. There are also extensive regions of the earth, where, owing to the general absence of ascending currents, the sky is normally serene. How, then, can we suppose that the stratum which produced the twilight glows continuously for several months, and intermittently for more than a year, and the corona for more than two years, could have been simply an elevated cirrus of the usual type, but formed round volcanic instead of ordinary dust? All analogy seems against it, and the frequency with which we find such remarks as that the haze was "peculiar," "indescribable," "smoky," "invisible except near the sun," "bore no resemblance to ordinary haze," together with records of the fact that it became more visible as the sun descended below the horizon (RUSSELL), contrary to the behaviour of ordinary cirrus, and its peculiar effects on the spectroscope and on astronomical definition, all point to something in its nature quite different from ordinary cloud.

We are, therefore, driven to the conclusion that the haze, if not entirely dust,

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* 'Indian Meteorological Memoirs,' vol. i., p. 408.

† This, of itself, constitutes a negative argument in favour of the haze being composed of the dust of solids.

was, at all events, so partially mixed with the vapour of the eruption that the latter did not, except at first, appreciably augment or interfere with the peculiar transmissive, reflective, and diffractive properties of the former. Ice spiculæ alone might account for the twilight glows, and possibly the corona, but they do not readily enable us to explain the coloured suns and many other peculiar optical features witnessed.

Some persons have suggested that the clouds may have been composed of condensed gaseous products of the eruption, besides water, such as sulphurous acid or hydrochloric acid; but although such gases were likewise probably expelled in large quantities, they would not be likely to exceed the volume of aqueous vapour, and would be subject to laws similar to those which would operate upon the latter.

They could not, therefore, have accounted for the entire phenomena, though it is very possible that they exerted some considerable influence.

That there was a copious evolution of sulphurous gases, is evident from the accounts of the eruption gathered by Mr. Verbeek from neighbouring localities in Java and Sumatra. Thus, at Tjanti, 29 English miles, there was a smell of sulphur at 6 a.m., August 27th. At Kroë, 134 English miles, the same occurred at the same hour. At Batavia, 94 English miles, and Serang, 48 English miles, there was a smell of sulphur all through the night of the 26th, and at the latter place again at 2 p.m. on August 27th.

Also on board the *W. H. Besse*, in the Strait of Sunda, "a strong smell of sulphur, making it difficult to breathe," was noticed during the eruption. To these may be added the following extract from a letter by Mr. F. A. Marten on board the *Slievemore*:—

"When we got to the Indian Ocean we sailed through large quantities of pumice stone, some pieces were a foot square and others like dust. I suppose they came from the earthquake at Java. The atmosphere was very unsettled, one minute it was blowing a gale, and the next it was a flat calm. The air was full of sulphur, and if we had the brasswork polished in the morning, it was black ten minutes after, like the ace of spades." *

Professor Kiessling, of Hamburg, who has studied the optical phenomena succeeding the eruption, particularly with reference to diffraction, considers that the *rôle* played by actual dust in producing these effects was inferior to that effected by the gaseous products of the eruption, since the latter would more readily form homogeneous clouds, homogeneity being a necessary condition to give brilliant diffractive effects, and he cites, in confirmation of this notion, the observation at Sciacca by Professor Hoffmann and Drs. Phillipi and Schultz towards the end of July, 1831, after the eruption of Ferdinandèa,† of the effects produced on certain silver instruments by the sulphurous products of the eruption.‡ That the condensed

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* MSS. dated Calcutta, Dec. 30, 1883.

† Another name for Graham's Island.

‡ 'Die Bewegung des Krakatau Rauches, im September, 1883,' von Professor J Kiessling.

products of such gases may have materially assisted the light pumice dust in producing the diffractive effects is very probable, but if, as we think, reflection played a very important part in producing the twilight glows, we cannot agree with Professor KIESSLING in attributing the effects mainly to the action of the former. The effects were probably due partly to one product and partly to another, the precise proportion due to each ingredient of the dust or smoke of the eruption being difficult to determine, owing to our ignorance of the exact composition of the smoke. Professor KIESSLING talks of the gases as if they would remain in the gaseous form at the height to which they, along with the finer solids, were ejected; but it seems hardly possible to doubt that, at a height of 100,000 feet, or even less, they would, owing to the intense cold, be condensed into solid forms. In a previous article in 'Das Wetter,' Professor KIESSLING speaks of the gases as probably sublimated in the upper regions.

Regarding the different spectra witnessed by Professor MICHIE SMITH at Madras, and Professor PIAZZI SMYTH at Edinburgh, which in the former case showed a marked absorption at the red end and a maximum of the rain-band, and in the latter case the red practically unimpeded, with the dry air-band at an immense maximum, it does not seem improbable that while at first, and in the tropics, the dust was mixed with a considerable quantity of water and vapour, by the time it reached the extra-tropics this had been absorbed by descent through the surrounding dry air. This circumstance would co-operate with its greater extension, in rendering the haze gauzy and nearly invisible, as was observed in the extra-tropics, instead of covering the sky and sensibly obscuring the sun, as was observed near the Equator.

We have summarily disposed of the theory that the dust was of meteoric origin, the marked commencement of the optical phenomena on an extensive scale after the grand eruption of Krakatoa on August 26th and 27th, and the succession of dates in different parts of the world, being alone enough to discountenance an hypothesis apparently quite unsupported by any positive evidence. Meteoric dust, moreover, is generally heavy compared with volcanic.*

In all that precedes † we have based our calculations on Mr. VERBEEK'S estimate of the amount of solid material ejected by Krakatoa, which he has only deduced inferentially from what actually fell on the land and sea adjacent to the volcano on August 27th and 28th. No account is taken by Mr. VERBEEK of what probably fell over the sea to the west and south-east,‡ but after simply calculating the total ejecta, from what fell near the volcano, to be 18 cubic kilometres (4½ cubic miles), he assumes that the amount of fine dust which remained in suspension in the

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* YOUNG, 'Comptes Rendus,' vol. xcvii., p. 1450.

† The preceding paragraphs were written before the writer had seen 'Krakatau,' Part II.

‡ During the night of the 30th August a rain of ashes fell on the ship *Meda*, between Ashburton River and Perth, at a distance between 50 and 100 miles off the west coast of Australia, and about 1,150 English miles S.S.E. from Krakatoa.

upper regions could not have exceeded one cubic kilometre (0·25 cubic mile), since the cloud of ashes, during the first three days after the eruption, let fall a considerable portion of its contents into the sea towards the west.*

It appears, therefore, that Mr. VERBEEK's estimate simply rests on the hypothesis that the dust which was left to float was $\frac{1}{18}$th of the total volume of matter ejected; and for this hypothesis we can see no evidence. Moreover, it leaves out two important considerations:—

(1.) The possibility that, in an extraordinary eruption of this sort, the ash which fell near the volcano might not afford much indication of the amount which was blown into the very finest dust, and, as facts show, was rapidly carried away from the spot.

(2.) The probable amount which fell on ships in the Indian Ocean for more than a week after the eruption, over an area which, to the west of the volcano alone, comprised from Mr. VERBEEK's own estimate, 1,100,000 square miles, and which from later information appears to have considerably exceeded this value. This amount must obviously be added to, and not (as Mr. VERBEEK would have it) subtracted from, what fell near the spot, on which alone he bases his calculation.

Allusion has already been made to the first of these considerations, and it does not seem improbable that, while the amount of ash which fell near Krakatoa was inferior to that which, on somewhat problematic data, is estimated to have fallen in the vicinity of Tomboro in 1815, the exceptional violence of the Krakatoa explosions (gauged by the area over which the sounds were heard), as compared with those of Tomboro, may have resulted in the expulsion of an unusually large quantity of the material in the form of the finest dust or smoke.

With respect to the second consideration, if we examine the accounts of the dust falling on ships traversing the Indian Ocean, we find that ash fell continuously from August 27th to 29th on the *Barbarossa*, about 860 English miles distant from the volcano; from midnight of August 27th to 11 o'clock in the morning of August 28th, on the brig *Brani*, about 968 English miles distant; for two days from the morning of August 28th on the *Arabella*, about 1,140 English miles distant; and from the afternoon of the 29th to the evening of the 30th on board the *British Empire*, about 1,800 English miles distant.†

To these may be added the observations on the *Simla*, nearly 1,200 English miles from Krakatoa, from August 28th to August 30th, between which dates a continuous fall is reported, in which the dust is spoken of as "falling in a constant shower like snow," and "a very large quantity of dust fell in the past night;" on board the *Salazic*, *County of Flint*, and *Lennox Castle*, August 27th to September 1st; and also that on the *Scotia* on September 6th, when at a distance of 3,313

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* 'Krakatau,' p. 157.

† *Ibid.*, p. 143.

English miles from Java, a slight fall is reported.* These all point to a fall not only of great extent but also of some appreciable magnitude.

If, then, we suppose that the area represented by these ships alone (excluding the *Scotia*) was 1,100,000 square miles, and was covered uniformly to a depth of only 5 millimetres, or ·02 inch, with dust, we should find for the total amount which thus fell 14·4 cubic kilometres ($3\frac{1}{2}$ cubic miles), an amount not very much less than that calculated by Mr. VERBEEK for the total amount of materials of all kinds ejected. It appears, then, that the finer dust, which was transported to more than 2,000 English miles from the volcano towards the west alone, might have equalled in amount what fell in its immediate vicinity; and it seems quite possible that as large or even a larger quantity was blown into such minute particles as to be capable of remaining in the highest regions of the atmosphere, and being carried right round the world in the tropical zone within a few days after the eruption.

It has been admitted that the quantity of dust or other solidified ejecta required to spread all over the world and cause the phenomena which were witnessed, constitutes, *primâ facie*, a possible objection to the hypothesis that all these optical phenomena were traceable to the effects of the eruption of Krakatoa; but it has been shown that the only ground on which this amount has been attempted to be estimated, is from the quantity of heavier material which fell near the spot, and that no account has really been taken of the large quantity of finer ashes dropped over a wide area of the Indian Ocean to the west, as well as of the velocity with which the finest material was carried westward. This last point is indeed most important, for if, as we find, a cloud-haze and smoky sunset were seen at Mauritius, the Seychelles, and Diego Garcia, on the evening of the 27th, unless we give an altogether abnormally high velocity to the smoke-stream by supposing it to start at 10 a.m. on August 27th, we must suppose that as fast as the material was shot up (from 2 p.m. on August 26th, when the *Medea* observed a smoke column ejected from the volcano to a height of 89,760 feet (17 miles) till at least noon on August 27th), the finest of it was carried westwards at a velocity of about 100 miles an hour. As dust continued to fall at the intermediate localities, and fell also on the following day upon ships at distances of more than 1,000 miles frem Krakatoa, such as the *Salazic*, *Simla*, *Brani*, and *Arabella*, it is evident that the clouds must have been nearly continuous, and about 2,000 miles in length.

We are thus led to conclude that, apart from vapour of water and gases, of which there was doubtless a large quantity, the amount of very fine dust, composed chiefly of pumiceous bubble plates, which was ejected and remained suspended in the air, may have been considerably more, perhaps four or five times the 4 cubic kilometres (1 cubic mile) we modestly allowed ourselves before we had been able thoroughly to examine the basis of Mr. VERBEEK's calculation.

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* Section I. (D), pp. 220, 221.

This permits us partially to remove the limitation we had assigned to the vertical extension of the dust film, and thus meet to some extent the objections put forward by M. VAN SANDICK, which are given in Section VI., p. 413.

Apart from the particular question of whether the ejecta which continued to produce the optical effects were solids, or sublimated gases, as Professor KIESSLING supposes, it may be pointed out that if it can be satisfactorily shown that the effects which were witnessed during the first 25 days after August 27th, 1883, over a zone bounded roughly by the tropics, were due to the grand eruption of Krakatoa which terminated on that day, their subsequent spread and appearance over the remainder of the globe presents little difficulty, since the former area represents nearly $\frac{2}{5}$ths of the entire surface of the globe.

(C.)

The next objection—viz., the difficulty of conceiving the dust to be capable of remaining in suspension in air of the tenuity which must exist at heights of 100,000 feet or more—is certainly, *à priori*, a legitimate one, and demands examination.

Apart from any force, such as electrical repulsion by the earth on particles that have been projected from it, which is supposed by Mr. W. H. PREECE, F.R.S., to have been an important factor in the present case,[*] we know that the rate of fall of small particles depends on their size, density, and the viscosity of the medium in which they are suspended.

The last factor is a very important one where the particles are small, and it is curious that in two well-known formulæ it is altogether disregarded, and the effects are supposed to depend entirely on the size and density of the particles and the density of the medium.

Thus, if we apply the ordinary hydro-dynamical formula,[†]

$$v = \sqrt{\frac{16}{3} \cdot \frac{\sigma - \rho}{\rho} \cdot g . a} .$$

for the terminal velocity of a spherical globule of density $= \sigma$ and radius $= a$, descending in a fluid of density $= \rho$, we shall find in the present case, where $\rho = \frac{1}{231600}$,[‡] $\sigma = 2$, and $a = \cdot 0003$ inch,[§] that $v = 15 \cdot 2$ inches per second—an evidently improbable result.

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[*] Section VI., p. 416.

[†] BESANT'S 'Hydro-mechanics,' p. 212.

[‡] The density of air at sea-level at 0° C. and 760 mm. pressure is sensibly $\frac{1}{772}$. (See FERREL'S Researches,' vol. i., p. 14.)

[§] From the radius of the corona. Section I. (E).

Again, if we take a formula given by Professor FERREL, in his 'Researches' (vol. ii., 1880, p. 77), in which the friction of the air is supposed to be allowed for, viz. :—

$$u' = 13{\cdot}54 \sqrt{\frac{\text{D.S.}}{s}},$$

where—

u' = the ultimate velocity in metres per second,
D = the diameter of the globule in centimetres,
S = specific gravity of globule,
s = specific gravity of the air at the given height compared with that at sea level,

we shall find from the same data a velocity of 9 inches per second, or 64,800 feet per diem—a result almost equally improbable.

Professor KIESSLING, however, has made experiments with smoke of ultra-microscopic fineness, and finds that in ordinary atmospheric conditions, it falls ·118 inch per minute, which, by an application of FERREL'S formula, would (according to Professor KIESSLING) be increased to ·394 inch per minute at a height of 20 kilometres (65,619 feet) (not far below the mean we have deduced for the glow stratum), and be equivalent to 17,389 feet per annum.

According to this result, the haze, if composed of particles of the same size as the smoke in the above experiments, would take about three years to fall through 50,000 feet.

Professor STOKES, P.R.S., has, moreover, given* an equation differing remarkably from either of the two preceding, and in which the viscosity factor is duly considered. It is :—

$$\text{V} = \frac{2g}{9\mu'}\left(\frac{\sigma}{\rho} - 1\right) a^2,$$

where σ, ρ, are the densities of the particle (supposed spherical) and the fluid respectively, a the radius of the particle, and μ' what Professor STOKES calls the "index of friction," and is defined by the equation

$$\mu' = \frac{\mu}{\rho},$$

where μ is the coefficient of viscosity. In the above equation, μ' is taken to be $(\cdot 116)^2$, though, according to later investigations, it is more nearly $(\cdot 14)^2$ in air at ordinary atmospheric pressure;† and since, according to CLERK MAXWELL, μ is

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* Cambridge 'Phil. Trans.,' vol. ix., part 2, 1851, p. 127.

† For this and the other details regarding the above formula, the writer of the present section is indebted to Professor STOKES, P.R.S., who directly communicated them.

independent of the pressure or density,* μ' varies inversely as ρ, so that, without material error, we may regard V as sensibly the same at lofty altitudes as near the earth's surface.

By the help of this formula we can arrive at some approximation to the inferior limit of the time of fall of the finer dust ejected from Krakatoa.

The following table presents the results obtained by inserting in the formula the different values of the semi-width of the particles, deduced from the angular diameter of the corona,† taking the density of pumice as 2.

Radius of Particles in Inches.	(1) With $\mu' = (\cdot 116)^2$.		(2) $\mu' = (\cdot 14)^2$.	
	Feet per day.	Time in falling through 50,000 feet.	Feet per day.	Time in falling through 50,000 feet.
(*a*) ·00003 (corona, 1st order) ..	68·4	2 years	46·8	2 years 358 days
(*b*) ·00007 (corona, 2nd order)	368·6	136 days	252	198 days
(*c*) ·00005 (mean of these) ..	189·5	263 days	129·6	1 year 20 days
(*d*) ·00002 (Flögel)	29·2	4 years 252 days	20	6 years 310 days

Thus we are led to conclude that, even on the extreme hypothesis that the corona was of the second order and the particles were spherical (in which shape they would offer the smallest resistance to the air), and their density twice that of water, the rate of fall would be remarkably slow; while, on the more probable hypothesis that the visible portion of the corona was entirely of the first order and the radii of the particles ·00003 inch (which is a mean between the values given by FOREL and other continental investigators), the rate would be such as to allow the finest and most homogeneous dust (even if spherical) to remain suspended between 100,000 and 50,000 feet for over two years. But there is every reason to believe, both from the examination by Mr. W. F. STANLEY‡ of the dust which fell on the deck of the *Arabella* on August 28th, in 5° 37′ S. 88° 58′ E. (1,140 English miles from Krakatoa), as well as from the researches of Professor BONNEY and Messrs. MURRAY and RENARD, that the majority of the particles which fell at a distance from the volcano were thin, over-blown bubble-plates of pumice, and so permeated with minute vesicles as to be of much less specific gravity than simple pumice dust.

Of the plates examined by Mr. STANLEY, which included twenty specimens, the majority were squares of from ·02 inch to ·002 inch in the side, and between ·00004

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* Since μ for a gas varies a little with the temperature, it would be somewhat smaller in the upper regions, and thus μ' would be similarly reduced.

† See Section on Corona, I. (E).

‡ 'Quar. Jour. Roy. Met. Soc.,' July, 1884.

inch and ·00008 inch in thickness. If this ratio between the areal and cubical dimensions were at all approximated to in the far more minute particles which were projected into and remained suspended at lofty altitudes, the particles whose width we have calculated from the corona to be ·00006 inch would not be spherical, but plates having a thickness considerably less than this quantity, and as they would tend to float with their flat surfaces horizontal, it can scarcely be doubted that they might remain suspended for a much longer period than that inferred from their rate of fall, assuming them to be spheres of ·00006 inch diameter. Apart, therefore, from the possible co-operation of electrical repulsion, we have ample grounds in favour of the theory that the finer dust which was ejected by Krakatoa into the loftier regions of the atmosphere would be suspended there for *at least two years.*

(D.)

The fourth objection, viz., that ordinary eruptions are not, as a rule, accompanied by such manifestations as were exhibited on the present occasion, is not a very strong one; since it is evident, from Section V., p. 384, on 'Previous analogous Glow Phenomena,' that, although several eruptions have occurred without being followed by atmospheric phenomena similar to those under discussion, nearly all the cases discovered, of unusual twilight glows, or coloured suns, or sky-haze, &c., coincide with the years or periods of great eruptions, and very few cases of great eruptions occur without corresponding atmospheric phenomena. Thus, in the period from 1600 to 1883, the following years were distinguished both for great eruptions and for extraordinary sky phenomena :—

1636, 1680, 1721, 1755, 1783, 1811, 1812, 1813, 1814, 1815, 1818, 1831, 1845, 1846, 1872.

It could not be supposed that every eruption was on a scale, or of a kind, able to produce effects similar to those which followed the unusually violent eruption of Krakatoa on August 26th and 27th, 1883. This argument against the volcanic hypothesis, therefore, is not a formidable one in the present case, and is met by the fact that the epochs of the greatest eruptions and of the most wide-spread sky phenomena for a period of fully 300 years generally coincide, and that cases of non-coincidence of both phenomena are rare. Had the means of intercommunication now at our disposal been available in former times, there seems little doubt that the coincidence would have been observed before it was remarked by Arago.

(E.)

To the hypothesis that the optical effects witnessed during 1883-4 were the result of the eruption of Krakatoa, or indeed of any volcano, it has been objected that certain appearances of a similar and unusual character were seen not only in May but in February, 1883, before any activity was manifested in the Javan or other area with which they could be associated.

Thus, Mr. NEISON [*] says: "The extraordinary sunsets began in Natal *in February*, 1883, but on a less grand scale, but gradually became more marked until *June.* Then for two months nothing was noticed." Again, "The sunsets of February, 1883, were sufficiently marked to induce me to try a water-colour sketch on February 8th. It was spoilt next day by two visitors."

Nobody else, as far as we are aware, saw any unusual appearances so early as this; the next one being Colonel WARD,[†] at Munich, who says: "The sunsets first attracted my attention and that of others on May 9th, 1883." He appears to have observed them particularly on the following dates: May 9th, 11th, 18th; June 7th, 12th, 15th, 20th, 21st; July 20th; August 16th.

Some of these latter are described by Colonel WARD in somewhat similar language to that employed by other observers of the extensive series after August 27th, such as May 18th, "Brilliant sunset and after-glow;" June 15th, "Brilliant sunrise and glow and orange sunset." But in both Mr. NEISON'S and Colonel WARD'S observations, which appear to be the only ones which could not be connected with any notable volcanic eruption, either in Java or elsewhere, there is no mention made of any of the other accompaniments, such as cloud-haze, coloured suns, or corona, which were so frequently present, locally and generally, after the May and August eruptions of Krakatoa respectively.

There seems, moreover, to have been a very curious anomaly in Mr. NEISON'S observations, which places us in the following dilemma, viz., that if his *ipse dixit* regarding the glows in Natal in February being similar to those which appeared locally after the minor, and universally after the major, eruption of Krakatoa in August, is to be taken as positive evidence against the general absence of other confirmatory observations in various parts of the world; we must consider his subsequent remark regarding the absence of remarkable sunsets in that region from September 5th, 1883, until January, 1884, as constituting a very curious exception, both to what occurred generally throughout the tropics, and to that reported from such adjacent localities as Cape Colony and the Transvaal.

Mr. BALLOT'S report upon the phenomena as observed in the Transvaal has already been given on pages 174 to 177; we need here merely give the reference to it, and state that Mr. NEISON'S evidence is distinctly at variance with that of adjacent observers, as well as with that from most other parts of the world, where the period during which the glows and other phenomena for the most part began, and reached their maximum intensity and extent, seems to have exactly coincided with that during which they were absent from Natal.

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[*] 'Knowledge,' June 6th, 1884.

[†] SYMONS'S 'Met. Mag.,' vol. xix., March, 1884.

Therefore, before evidence coming from one observer in Natal can adequately be discussed in its bearings on the question of the origin of these remarkable sunsets, some explanation is requisite to account for their anomalous absence or diminished brilliancy in Natal alone. Certainly, until this has been thoroughly investigated, the evidence from Natal alone leaves the question *in statu quo*, for we cannot arbitrarily accept the observations in February, and exclude those in November and December.

Among later observations which occurred at a considerable distance from Krakatoa or the Indian Ocean, and which cannot be attributed directly to the activity manifested by that volcano in May and June, 1883, may be mentioned those of the *Viola,* off the west coast of Africa, on May 24th and 27th, which were possibly due to Sahara dust.[*]

Logansport, Indiana, August 13th, 1883 :[†]—"Yellow sunset, with a peculiar streak of the same colour, which changed into a glorious red after sunset."

Nashville, Tennessee, August 22nd :—" A beautiful sunset."

Crowborough, Sussex, August 27th, where Mr. C. L. PRINCE says :—" I noticed a precisely similar phenomenon, as regards various tints and their relative positions, as I did on so many mornings during the winter months (later on), which strengthens my opinion that aqueous vapour under exceptional conditions has had more to do with them than volcanic dust.[‡]"

Colonel M. F. WARD,[§] August 16th, 1883, at Munich, says :—" Brilliant sunset and after-glow."

After these come some early sporadic observations of Mr. ROLLO RUSSELL'S, at Haslemere, before the first of the grand and continuous series commencing November 8th, and which appear soon after this date to have been seen all over western Europe. Thus, on September 8th, he notices in his diary, " a fine red sunset with *after-glow*," an expression which Mr. RUSSELL says he was not in the habit of using, and employed then for the first time. Again, on September 9th, he notices " a great succession of small cirrus-like masses," and " very high small cirro-strati, vastly higher than the cirrus." Here there appears to be undoubted reference to what was afterwards observed so generally in connection with the twilight glows and other effects all over the world, and was denominated " cloud-haze." Similar sunset glows were seen by the same observer on September 16th, October 3rd, 20th, 21st, 22nd.

Regarding the earlier observations of both Colonel WARD and Mr. NEISON, it seems scarcely probable that they had any connection with the eruptions of Krakatoa in 1883, the time which it would take the material to spread into the extra-tropics (to judge by analogy from the interval between the grand eruption of

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[*] See Section II., p. 265.

[†] 'Met. Zeitschrift,' vol. i. (1884), p. 187.

[‡] The writer of the present section has had the advantage of personally consulting Mr. PRINCE regarding the above and other observations.

[§] SYMONS'S 'Met. Mag.,' vol. xix., 1884, p. 23.

August 27th and the subsequent general appearance of the optical effects in Europe in November) being too long to allow even those in June to be attributable to the preceding eruption of Krakatoa on May 20th. On the other hand, those, in August, and from September 8th onwards, of Mr. RUSSELL's, might possibly be due to a spread of the material ejected during the May eruption into higher latitudes; the intervals between the respective eruptions and appearances being somewhat similar, as follows:*

Eruption.	Mr. Russell's First Observation.	Mr. Prince's Observation.	Interval in Days.
May 20th	Sporadic, September 8th	.. ..	111
,, ,, ...	.. .. ..	August 27th	99
August 27th	General, November 23rd	.. ..	88†

While, however, it is fully admitted that there is considerable difficulty in accounting for the earliest glows seen by Mr. NEISON and Colonel WARD, which appeared to them to be similar to those seen generally after, and which we attribute to the August eruption of Krakatoa, we do not think that the fact that one or two such apparent anomalies existed (even granting that they were identical in every respect with the more general appearances), constitutes a serious objection to the theory that the general appearances were connected with the grand eruption of August 26th and 27th. A perusal of the general list, and a consideration of the converging lines of proof in favour of Krakatoa as a common origin of the brilliant appearances seen soon after August 27th throughout the tropics, and later on in higher latitudes, leave an impression on the mind too deep and convincing to be eradicated by such sparse, uncertain, and in part contradictory, evidence to the contrary. The *onus probandi* or *non probandi* must lie in this case with those who consider that Mr. NEISON's and Colonel WARD's earlier observations of remarkable glows at twilight are of such importance and identity with those in which *four distinct phenomena* were nearly everywhere recognised and conjoined, that they can be unhesitatingly accepted as subversive of the vast series of observations and facts which favour the view that the latter were due to the effects of an unparalleled eruption which occurred in the neighbourhood of Sumatra and Java on August 26th and 27th, 1883.

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* Another supposition is given in Section III., which connects them with the August eruption.

† It may be noted as a curious coincidence, and possibly confirmatory of the supposed time taken by the ejecta from a volcano in the Javan Seas to reach England, that the first general appearance of optical phenomena, similar to those under discussion, after the great eruption of Tomboro in Sumbawa on April 7th, 1815, was on June 28th and 29th in the same year, an interval of 82 days. The eruption was on a scale similar to that of Krakatoa in August, 1883.

Summary of the Evidence in favour of the Connection of all the Optical Phenomena with the Eruptions of Krakatoa.

We now present a brief summary of the positive evidence which tends to show that all the optical phenomena which appeared in 1883 and thenceforward, were direct consequences of the eruptions of Krakatoa in the same year.

Before doing this, reference must be made to an eruption of Mount St. Augustin, in Cook's Inlet, Alaska, on October 6th, 1883, which has been supposed by some to have either produced, or aided in producing, the optical effects witnessed in America and Europe in November.

We cannot, however, believe that this eruption, large as it was, had any but a very partial influence on the effects witnessed in our latitudes; for if it had been in any way comparable with that of Krakatoa, we should have expected to find indications of its effects at those places nearest to it, such as Siberia, British Columbia, and Canada. We find, however, that the unusual twilight glows and accompanying phenomena were not observed in British Columbia until November 23rd,* or over Canada or Iceland until the end of November; and they did not arrive at Kiachta, in Siberia, until December 11th, the progression thither being evidently by way of Europe.

Moreover, the phenomena were propagated up the western American coast from south to north, appearing in California and the southern States early in October, and spreading over the eastern States by the end of the month, some time before they appeared in British Columbia and Canada.

We cannot suppose that the material would spread so slowly from Mount St. Augustin as not to affect places situated 35° E. of it, until 48 days had elapsed, or Kiachta, 100° to the west, until the lapse of 66 days. Besides, by October 6th, a belt of the earth from at least 35° N. to 45° S. had been entirely covered by the appearances.

We shall now proceed briefly to review the circumstances which tend to show that all the optical phenomena simultaneously made their appearance, both sporadically after the minor, and universally after the major, eruptions of Krakatoa in 1883, in such a manner as to show that they were direct consequences of the finer material ejected by this volcano, at these respective epochs.

In order to obtain a clearer view of the relation of these two outbreaks to the phenomena which succeeded them, we shall separate the phenomena into two groups: (A) those which can be directly associated with the period of minor activity of the volcano; and (B) those which occurred in the neighbourhood of the volcano, and in the surrounding seas, immediately after the fearful outburst which terminated on August 27th.

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* See General List, Section II., p. 297.

(A) Regarding those which are connected with the period of minor activity, two points are noticeable : (*a*) there does not seem to be any evidence to show that before May 20th, 1883, the commencement of the period of minor activity of Krakatoa, any appearance of coloured suns,* coronal appendage, or peculiar and lofty cloud-haze occurred in the Indian Ocean, or indeed in any part of the world, in 1883 ; (*b*) that while there seems to be clear evidence of the appearance of most of the optical phenomena after May 20th in the Indian Ocean, they appeared sporadically, sparsely, and intermittently, compared with those which followed the great eruption of August.

To show their relation to the activity of the volcano, we shall here insert the dates on which signs of its activity were either seen or heard† in the neighbourhood :

May 20th—23rd : The minor eruption began on May 20th, during which the volcano shot up a column of smoke, estimated by the Captain of the *Elisabeth* at over 36,000 feet high.

The noise of the eruption was heard at distances varying from 170 to 220 English miles on the west ; to Singapore, 522 English miles to the north ; and to upwards of 90 English miles on the east.

Several ships, including the *Elisabeth*, reported falls of ashes ; while even at Kroë, in Sumatra, 134 English miles distant, ash fell so thickly as to obscure the sun. The descriptions, in fact, show that it was in many points very similar to the great eruption of August 26th and 27th, only of less violence. At this time one crater alone (Perboewatan) was in eruption.

June 19th : Two craters (Danan and Perboewatan) were in continual eruption up to the 29th and 30th, when "the sounds were very intense."

August 11th : Three craters (Danan, Perboewatan, and Rakata) were all in eruption, throwing up enormous columns of smoke.

August 14th : The ship *Madura*, passing some miles from the volcano, was much inconvenienced by the ashes which fell on her. The darkness was so great that the compass lamps had to be lit, and the ship remained four hours in the ashes.

August 23rd : The ship *Prinses Wilhelmina* saw a powerful column of smoke rise from the crater, and experienced an abundant rain of ashes.

August 25th : Ashes fell at Teloek Betoeng (ashes, in opposition to fine dust which had frequently fallen there during June, July, and August).

Corresponding with the May eruptions we have the observations on the *Elisabeth* and *Actæa* on May 20th, already detailed under Section I. (c), p. 200, together with one on the *Lord Warden*, on May 24th, in 39° 18′ S. 93° 25′ E. (sunset peculiar, dark blue-green tints on the horizon), and another on *Her Majesty* on May 26th, in lat. 3° 8′ S., long 90° E. (at 9 p.m., thin haze over the sky, through which the larger stars shine), in the Indian Ocean.

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* Mr. NEISON's and Col. WARD's observations refer only to bright sunsets.

† These data are all extracted from 'Krakatau,' by Mr. VERBEEK, pp. 9–31.

There seem also to have been some sporadic observations, apparently connected with the period of increased activity of Krakatoa, during the latter part of June.

Thus the observations on the *Belfast* on July 16th and 17th, in lat. 9° to 11° S., long. 85° 53′ E., point clearly to the simultaneous occurrence of an unusual yellow glow, blue moon, and cloud-haze, about 1,750 English miles from the volcano. If, therefore, it be conceded that these latter, like their predecessors in May, were connected with the effects of the continuous, though minor, activity of Krakatoa during this period, it is reasonable to suppose that any unusual appearances which were manifested at more distant localities bordering on the Indian Ocean, such as at Pamplemousses, in Mauritius, on July 20th,* or even at Natal, by Mr. NEISON, after May, might have been due to an extension of the fine ejecta towards those parts, similar to, though on a reduced scale compared with, what occurred after August 26th.†

Again, on August 22nd, the date on which the activity, which culminated on August 26th and 27th, appears to have recommenced, we have the remarkable observation from the *Charles Bal*, already referred to under Section I. (D), p. 219, when in 15° 30′ S. 105° E., in which mention is made of a milky-white appearance of the sea, and a white haze or silvery glare in the sky, which seemed to have extra light in it (between 9 and 10 p.m.) similar to when the aurora is showing faintly. This was repeated on the 24th.

The similarity of this to the observations in 1831, and to the subsequent observations of the glow in the extra-tropics, which at first was mistaken for the aurora, scarcely needs demonstration.

From this date up to the 27th certain sporadic observations are reported of an apparently similar character at greater distances, which may possibly have been due to an extension of the material ejected during this period; but when we come to August 27th, the day after the series of great explosions, which commenced at 2 p.m. on August 26th, there is at once a very marked increase in the intensity, variety, and area over which the appearances were manifested; and it is only after this date that we find evidence of the extraordinary general westward propagation of the haze material, which the sporadic and sparse data hitherto available had only partially shown, though, even so, they had agreed with the dominant westward trend of the dust and steam which was exhibited from the moment these left the volcano, both in its earlier and in its later eruptions.‡

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[*] 'Proc. Maur. Met. Soc.,' August 23rd, 1883.

[†] This, of course, does not touch upon the alleged appearance of unusual glows in Natal as early as February, according to Mr. NEISON, to which reference has already been made.

[‡] From the height to which the material was ejected during the May eruptions, by the measurement on board the *Elisabeth*, and that in the August eruption, which far exceeded it, we must infer the upper westerly current to be of some considerable depth as well as constancy. See Section III., p. 312 *et seq*.

(B) In proportion as the eruption of August 27th exceeded in violence and amount of ejecta the minor activity in May and June, so we have considerably more proof of the co-existence and co-extension from the neighbourhood of Java of all the optical appearances which succeeded it. The fact that coloured suns and twilight glows were not everywhere coincident, has been shown in another section to be no proof against their common source, since it is most probable that the haze-material was not uniformly distributed, but was, owing to the spasmodic character of the eruptions, wafted along in lenticular clouds, separated by intervals where the material was less dense; so that while in some places the sun's light was dimmed or rendered silvery (which occurred mostly near the Equator and along the parallel of Krakatoa where the denser portions would congregate), in others, the material cut off only certain rays; while in others, again, it was of sufficient delicacy to allow reflection to dominate over obstruction and to permit of the appearance of brilliant twilight glows.

By differences in the general position and movement of such clouds at first, and their subsequent aggregation into a more homogeneous stratum, the apparent want of uniformity in the character of the appearances during their earlier development is readily explained.

The circumstances relating to the spread of all the optical phenomena together, from the neighbourhood of Krakatoa, immediately after August 27th, are so numerous and interwoven, that we shall not attempt any further review of the distribution, which is worked out in detail in Section II., p. 269, but merely refer to some which were witnessed during, or shortly subsequent to, the eruptions, in adjacent districts of Sumatra and Java, and which were evidently due to the materials ejected at the time. In mentioning these, it must be remembered that as the attention of persons in these localities was taken up mainly with the darkness, detonations, sea waves, and other phenomena of a much more serious and awe-inspiring character than the colours of the sun and sky, the fact that these latter were noticed at all, is strong proof that they were of an unusual and special nature. For example, at Serang, we are told* that on August 27th, "à 4 heures des lampes brûlaient encore, quoique, à ce moment il régnât une *lumière crépusculaire*." At Buitenzorg, on the same day, before the ashes fell, the sky was livid yellow.

At Teloek Betoeng, at 9.30 a.m. on August 27th, the sky in the direction of Krakatoa was the colour of copper.

At Semanka, on August 26th, "la nuit entre 4 et 5 heures une grande étendue du ciel presentait *une clarté rougeâtre*;" and on board the barque *W. H. Besse*, in the log-book of the first officer, occurs the following remark, when the ship was off St. Nicholas Point, in Java, 44 English miles from Krakatoa, on the morning of August 27th:—"The sun, when it rose, had the appearance of a ball of fire; the air so smoky, could see only a short distance."

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* All these are extracted from 'Krakatau,' Part I.,p. 40, *et seq.* by Mr. VERBEEK, and are left unnoticed by him in his review of the optical effects in Part II. of that work.

Then, in 5° 38′ S. 106° E., Mr. J. WOOLDRIDGE, writing in the 'London and China Telegraph' (January 16th, 1884), thus describes the scene. After alluding to the eruption on August 27th, 1883, of the volcano, which was within sight, he says:—"At sunset the heaven presented a very terrible appearance, the dense mass of clouds covered with a blood-red appearance, the sun being seen through the volumes of cloud being discharged by Krakatoa."

He also mentions the clouds at sunset being red and yellow. Even on the 26th we have some similar observations from neighbouring ships. Thus, Captain STRACHAN, of the *Anerley*, when passing through the Straits of Banca, saw "an arch of light at sunset stretching to the zenith."

In the evening of the same day, after the eruption had continued for some hours, the *Ardgowan*, in lat. 7° 54′ S., long. 85° 37′ E., notices a "flare" and "coppery-red colour" at sunset; and the *Barbarossa*, 1° 42′ S. and 93° 12′ E., at sunset observed "the whole sky a peculiar red like bright polished copper."

On the 27th the *Simla*, in 5° 35′ S. 88° E., observes the sky as "very hazy," and the barque *Jonc*, in lat. from 4° 46′ S. to 7° 45′ S., long. 90° to 93° E., Captain REID noticed that, from August 26th to 28th, "the sun on rising had a very strange appearance, as though the earth were on fire."

On August 27th, besides the observations we have already given from districts in Sumatra and Java adjacent to the volcano, we hear that at Batavia the sun on emerging from the cloud of smoke of the eruption was green,[*] and Captain STRACHAN, of the ship *Anerley*, near N. Watcher Island, about 90 English miles north-east of Krakatoa, at 4.30 a.m., says:—"Before daybreak the whole heavens were lighted up by a pale yellow light of changing hues, which lit up the entire ship and turned everything on board the same colour. This lasted 45 minutes and then died out. Daylight, such as it was, broke about 6 a.m."

At a considerably greater distance, but still within sound of the eruption, we have the following account from Labuan Island, in which the cloud-haze and a green sun were clearly recognised by Captain the Hon. F. C. P. VEREKER, of H.M.S. *Magpie*, among the effects of the outburst[†]:—

"The noise of the detonations caused by Mount Krakatoa, resembling distant heavy cannonading, was distinctly heard by us and the inhabitants of the coast as far as Banguey Island on August 27th. The weather at the time was also much unsettled, with thick hazy weather, and peculiar clouds to the southward, and the sun, while at a low altitude, assumed a greenish hue for several days."

Further off, again, towards the west, we have the series of observations which include a green sun at Mullaittivu and Kokkulai, in Ceylon, gorgeous sunsets at Diego Garcia, the Seychelles, Réunion, Rodriguez, and Mauritius, and a smoky appearance and haze at the Seychelles, the St. Brandon Rocks (Cargados Garajos), and Diego Garcia.

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[*] 'Batavia Dagblad,' 'Ceylon Observer, November 2, 1883.

[†] 'Nature,' vol. xxix. (1883), p. 153.

On the 28th the area embraced by the appearances was more extensive, while ships not far from Java, such as the *Ida,* 1° N. 108° 42′ E., *Charlotte,* 7° 18′ S. 106° 12′ E., *Simla,* 6° 12′ S. 88° 17′ E., *Barbarossa,* 3° 48′ S. 93° 30′ E., and *Salazic,* 9° S. 93° E., observed "a blood-red sunset with uninterruptedly hazy air for several days thenceforward," "hazy air," "sky very hazy," "a yellow glow and clear silvery light," "the sun reddish and the sky white," respectively, the glows appearing at Mauritius, the Seychelles, &c., with more brilliancy than before, and continuing thenceforward.

It would be unnecessary for our present purpose to follow the distribution any further, as it is already given in Section II., p. 271, and may be gathered in detail from the general list.

There are some special cases, however, worthy of notice, in which the *community* of all the phenomena is clearly shown by two or more of them appearing together at the same place soon after August 27th.

Thus, the *Corona,* on August 31st, in 1° 19′ S. 20° 55′ W., reports "a metallic haze over the sky, the sun shining through it quite coppery."

On August 30th a cloud-haze, coloured sun, and corona were seen at Tokio; and at Carupano, San Christobal, and Trinidad, on September 2nd, blue suns and red glows at sunset were observed.

On September 1st, at Cape Coast Castle, and on the *Queen of Cambria,* in 9° S. 28° W., we have the sun white through haze; and the remarkable observation at Guayaquil, from September 1st to 5th, uniting the haze, silvery sun, and corona. On September 3rd, the *Olbers,* 7° 20′ S. 33° 9′ W., notices a red glow before sunrise, and at 7 a.m. a pale blue sun; and the observer on board the *Queen of Cambria* remarks, "the haze that is still in the air was fiery red before sunrise, and the sun appeared dazzling white when it rose."

On September 5th, at Honolulu, the Hon. Mr. and Mrs. Whitney noticed a "green sun" and strange colours in the west; the Rev. Sereno E. Bishop reported a surprising spectacle of portentous masses of coloured light at and long after sunset, and this was repeated with slight variations of brilliancy thenceforward for many nights and days.*

Two more observations in the Indian area are worth notice, as they show that the connection between the several phenomena was manifest to the observer, viz., Mr. Ladd's observation in the Red Sea, in September, 1883, mentioned in Section I. (c), p. 205, of a green sun and moon, and of the latter being "covered with thin cirro-stratus over which the after-glow was cast;" and the Rev. W. R. Manley's letter from Ongole, dated September 14th, in which a green sun, a twilight glow, and a corona round the moon, 30° in breadth, are mentioned.

If to these special cases be added the numerous examples in the general list,† in which, as time progressed, either one or other of the phenomena was observed over an

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* "Equatorial Smoke Stream," 'Hawaian Monthly,' May, 1884.

† See Section II., p. 279.

ever-widening area, while they continued to be visible over the Indian Ocean and the neighbourhood of Java, where they were first observed in any quantity after the great eruption of August 26th and 27th; and if it be noticed that in most places where they appeared after this date, they continued to appear for months together, and not merely sporadically and ephemerally as after the minor eruptions, there will be no ground left for doubting either their common origin and its position, or their common extension and identity in different parts of the world.

Summary of Part IV., Section VII.

We shall therefore conclude by summarising as briefly as possible the chief reasons for considering all the unusual optical effects (including those seen in extra-tropical latitudes) which made their appearance in September, October, November, and December, 1883, and in part thenceforward up to the end of 1885, to be direct consequences of the eruption of Krakatoa in August, 1883:

(1.) The fact that the entire range of optical effects, including the brilliant and unusually prolonged glows at sunrise and sunset, the blue, green, silvery, and coppery appearance of the sun, the lofty cloud-haze, and the large corona round the sun and moon, made their appearance locally after the minor, and universally after the major, eruptions, in such a manner as to show that they all had a common origin both in space and in time, and that this origin was the neighbourhood of the volcano Krakatoa in May and August, 1883.

(2.) That the twilight glows, coloured sun, cloud-haze, and corona (the latter being less frequently observed at first, though not less widely spread than the others) appeared for the most part progressively along and symmetrically with respect to, a line extending west from Java and parallel with the Equator, the motion along this line being evidently real, since in Section III. (where the distribution in space and time is worked out in detail) they are shown to have appeared at places where they had not previously been seen, or to have reappeared where they had temporarily declined, after they had made one complete circuit of the globe, and at substantially the same rate in longitude as at first.

(3.) The unusual character, duration, and universality of the cloud-haze, its effect on astronomical definition, its general similarity to attenuated volcanic smoke or dust, and the general testimony in favour of the fact that this haze was the proximate cause of all the other optical phenomena.

(4.) The unusual character, duration, and large size of the coronal appendage to the sun, showing that the haze which caused it was composed of very small particles, its independence of all ordinary meteorological changes, its survival of the glows, and the gradual disappearance of both haze and corona in the summer of 1886.

(5.) The extraordinary height to which the ejecta of the eruption of Krakatoa on August 26th were observed to ascend, and the fairly close agreement of this and other direct observations with the height of the stratum as calculated from the duration of the twilight glows in the tropics and in the neighbourhood of the volcano. Also the fact that the greatest mean height of the stratum was observed at first in the tropical and Indian area, and that as time went on a gradual subsidence of the material took place everywhere, as would be likely to occur if it were dust ejected from below into the upper regions.

(6.) The evidence given already in Section V., p. 384, on "Previous Analogous Glow Phenomena" which in many cases are shown to be directly consequent on eruptions of neighbouring or distant volcanoes; as also the phenomena observed by WHYMPER in the Andes, and certain effects noticed in the vicinity during the eruption of Krakatoa, and recorded in Mr. VERBEEK's 'Krakatau.'

There are many minor considerations which point the same way, and which have been incidentally mentioned or implied in the foregoing sections.

Amongst others, the *continuity* of the propagation of the material and the corresponding optical phenomena, from their first general appearance in the Indian Ocean, after August 26th, including their successive revolutions round the globe from east to west within the tropics, and their subsequent spread from west to east over northern Europe and Asia.

Also the fact that while Bishop's Ring appeared sporadically in a few places after the May eruptions of Krakatoa, it seems never to have been observed by such careful observers as Professor von BEZOLD, M. THOLLON, of Nice, and Mr. T. W. BACKHOUSE, of Sunderland (a halo observer for 25 years), until the general arrival, at their respective localities, of the haze and other optical phenomena which succeeded the August eruptions.

There are one or two minor points which present opportunities for further research; for example, the precise effects of dust, or dust and vapour, upon sunlight. Professor TYNDALL's, Professor KIESSLING's and Captain ABNEY's experiments on the dispersion and diffraction of light by small particles, have advanced the question considerably, but much remains to be done.

Amongst others, further information would be desirable on the following points:—

(1.) The inferior limit of the size of ice particles produced from vapour.

(2.) Observations as to the rate of fall of small particles in rarefied air.

(3.) The duration of ordinary coloured twilights under different meteorological conditions.

(4.) The motion of the upper cloud systems near the Equator.

(5.) The meteorological and physical conditions under which ice crystals would produce diffraction coronæ and not refraction halos.

E. DOUGLAS ARCHIBALD.

PART V.

REPORT ON THE MAGNETICAL AND ELECTRICAL PHENOMENA ACCOMPANYING THE KRAKATOA EXPLOSION.

Prepared, at the request of the Kew Committee, by G. M. Whipple, B.Sc., *Superintendent of the Kew Observatory, Richmond, Surrey.*

The materials placed in the hands of the Kew Committee for the prosecution of this inquiry were as follows:—

(*a.*) Magnetograph curves from the under-mentioned observatories for the following dates:

	1883.
Batavia	August 26th–27th.
Colába, India	,, 24th–September 2nd.
Lisbon	,, 27th–30th.
Mauritius	,, 27th–30th and September 16th–18th.
Melbourne	,, 23rd–29th.
Parc Saint Maur, Paris ..	,, 25th–30th.
Pawlowsk (St. Petersburg)	,, 26th–28th.
Stonyhurst..	,, 24th–30th.
Vienna	,, 26th–29th.
Zi-Ka-Wei, China.. ..	,, 27th–29th.
Kew, Richmond	,, 27th.

(*b.*) Copy of letters from T. W. Backhouse, Baron V. Heerdt, Dr. Van der Stok, and others.

(*c.*) Abstracts from communications to the Press.

From the correspondence submitted, we have made the following abstracts, giving the opinions of various writers as to the occurrence, or otherwise, of magnetic disturbance simultaneously with the outbreak of Krakatoa.

Dr. MELDRUM first called attention to a magnetic disturbance recorded at Mauritius between August 26th and 30th 1883.

Lieutenant POORTMAN, at Batavia, remarked that the magnetic curves were very much disturbed during the rain of ashes on August 27th.

In answer to subsequent inquiries, the Rev. MARC DECHEVRENS, of Zi-Ka-Wei, wrote doubtfully of a small disturbance on August 27th, and Captain J. DE B. CAPELLO referred to magnetic movements on August 27th and 29th.

On the other hand, Mr. R. L. J. ELLERY, of Melbourne, Mr. C. CARPMAEL, of Toronto, and M. HOOREMAN, of Brussels, affirmed that their instruments did not register any disturbance.

The Rev. S. J. PERRY, of Stonyhurst, merely remarked that, although the curves for the 27th were slightly disturbed, other dates exhibited nothing noticeable.

With the view of tracing out what effect, if any, was recorded by the magnetographs on or about August 27th, 1883, the curves were all collected, and copies traced on a sheet ruled to Greenwich Mean Time; the local times, indicated on the various curves, being converted into Greenwich Mean Time, civil reckoning for the purpose.

As all the curves, with the exception of that from Paris, were produced by Kew-pattern magnetographs, the time scales are practically identical throughout, and hence, easily reproduced on one sheet. The Arc scales are also comparable; but the Force scales have various, and in some cases unknown, values; therefore, the curves representing the changes experienced by these instruments cannot be regarded as proportionate to the changes in the intensity of the components of the earth's force at the different stations.

At the first glance at the diagram (Plate XL.) it will be seen that, with the exception of 8 or 10 hours at the commencement of the Batavia trace, the curves for August 27th are very quiescent, and do not indicate anywhere the presence of the abrupt variations in both the direction and the intensity of magnetic force usually accompanying magnetic storms. We must consider independently the curve alluded to above, the movements in which are attributed by the local observer to the magnetic nature of the volcanic ash falling around the Batavia Observatory at that time.*

A gentle, steady, double oscillation of the magnets is shown in each of the curves, excepting those from Melbourne and Paris, at both which observatories the action of the instruments appears to be somewhat wanting in sensibility. This oscillation

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* See letter from Dr. VAN DER STOK on p. 475.

differs remarkably from ordinary magnetic movements, inasmuch as it is a well-known feature in the latter, that they are almost simultaneously produced at different parts of the earth's surface. Good examples illustrating this fact are exhibited in the plates published in the papers by Professor W. G. ADAMS, in the British Association Reports for 1880 and 1881.

On August 27th the disturbance wave seems to have passed from the east towards Europe, and is recorded later and later the further it progresses westward.

The wave of solar diurnal change which the magnet undergoes at every station produces a somewhat similar effect to that exhibited by the curves, but its period is usually better defined.[*]

In the curves drawn for the three elements at most of the observatories we have succeeded in selecting a number of common phases, and have measured the times of their occurrence at the different stations.

They are given in Tables I., II., III., and are also shown graphically on Plates XLI., XLII., and XLIII.

TABLE I.

Transits of Phases of Magnetic Movement, as recorded by the Declinometers.

August 27th, 1883.

Station.	Time of First Phase.	Interval.	Time of Second Phase.	Interval.	Time of Third Phase.	Interval.	Time of Fourth Phase.
	G.M.T.		G.M.T.		G.M.T.		G.M.T.
	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.
Zi-Ka-Wei ..	5 30 a.m.	0 40	6 10	1 0	7 10	2 40	9 50
Colába	6 42	0 26	7 8	2 0	9 8	—	—
Mauritius ..	7 8	1 12	8 20	1 10	9 30	0 40	10 10
Pawlowsk ..	10 30	0 23	10 53	1 2	11 55	2 0	13 55
Vienna	12 18	0 20	12 38	1 10	13 48	1 52	15 40
Kew	13 23	0 27	13 50	1 20	15 10	2 20	17 30
Stonyhurst ..	13 30	0 20	13 50	1 35	15 25	2 10	17 35
Lisbon	—	—	—	—	16 0	1 50	17 50
Pará[†]	19 50	—	—	—	—	—	—
Means ..	..	0 32	..	1 20	..	1 56	..

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[*] The undisturbed solar diurnal curve of Declination at the Kew Observatory for August has been drawn at the foot of the diagram for the purpose of comparison.

[†] Eye observation only.

TABLE II.

Transits of Phases of Magnetic Movement, as recorded by Horizontal Force Magnetographs.

August 27th, 1883.

Station.	Time of First Phase.	Interval.	Time of Second Phase.	Interval.	Time of Third Phase.	Interval.	Time of Fourth Phase.
	G.M.T. h. m.	h. m.	G.M.T. h. m.	h. m.	G.M.T. h. m.	h. m.	G.M.T. h. m.
Zi-Ka-Wei	5 35	0 35	6 10	1 8	7 18	0 22	7 40
Colába	6 10	0 40	6 50	0 30	7 20	0 22	7 42
Mauritius .. .	Trace undisturbed.						
Pawlowsk	8 35	0 47	9 22	2 43	12 5	1 15	13 20
Vienna	11 10	1 10	12 20	0 35	12 55	1 0	13 55
Kew..	13 35	0 25	14 0	0 30	14 30	1 30	16 0
Lisbon	14 15	—	—	—	—	—	—
Means	..	0 43	..	1 5	..	0 54	..

TABLE III.

Transits of Phases of Magnetic Movement, as recorded by the Vertical Force Magnetographs.

August 27th, 1883.

Station.	Time of First Phase.	Interval.	Time of Second Phase.	Interval.	Time of Third Phase.	Interval.	Time of Fourth Phase.
	G.M.T. h. m.	h. m.	G.M.T. h. m.	h. m.	G.M.T. h. m.	h. m.	G.M.T. h. m.
Zi-Ka-Wei	5 10	0 43	5 53	0 47	6 40	1 8	7 48
Colába	6 10	0 25	6 35	0 43	7 18	0 35	7 53
Mauritius	7 10	1 15	8 25	0 55	9 20	0 40	10 0
Pawlowsk	9 30	0 55	10 25	0 20	10 45	0 25	11 10
Vienna	—	—	12 0	0 30	12 30	1 15	13 45
Kew.. ..	12 30	0 42	13 12	0 31	13 43	0 52	14 35
Lisbon	14 10	1 10	15 20	2 0	17 20	0 40	18 0
Means	..	0 52	..	0 49	..	0 48	..

Owing to the fact that no two of the stations lie exactly on the same great circle of the earth passing through Krakatoa, we are unable to estimate directly the velocity of transit of the magnetic disturbing wave between any two of them; but, taking the distance of each from the point of eruption, we can compute a velocity along each line. The only datum available, however, from which we can calculate these velocities of transmission, is the time of the explosion as determined from barometric data by General STRACHEY, viz., 2 hours 56 minutes a.m. Greenwich Mean Time, August 27th.*

The first phase in the disturbance-wave in the curves, if traced back to Krakatoa, indicates, with a fair degree of accuracy, that the magnetic movement had its origin at about the same time. The later phases appear to have arisen at subsequent periods; and arbitrary times of starting have been deduced from the mean intervals which have been calculated from the Tables I., II., III., as having elapsed between the successive phases of the disturbance.

These have been assumed to be as follows:—

TABLE IIIA.

	First Interval.	Second Interval.	Third Interval.
	h. m.	h. m.	h. m.
Declination	0 32	1 20	1 56
Horizontal Force	0 43	1 5	0 54
Vertical Force	0 52	0 49	0 48
Means	0 42	1 5	1 13

	h. m.		h. m.		h. m.	
Time of origin	—		—	=	2 56	G.M.T. for First Phase.
Assumed time of origin ..	2 56	+	0 42	=	3 38	„ „ Second Phase.
„ „ ..	3 38	+	1 5	=	4 43	„ „ Third Phase.
„ „ ..	4 43	+	1 13	=	5 56	„ „ Fourth Phase.

			G.M.T. h. m.
1st movement causing	maximum	in Declination curve	2 56 a.m.
2nd „ „	minimum	„ „	3 38 „
3rd „ „	maximum	„ „	4 43 „
4th „ „	minimum	„ „	5 56 „

In the case of the forces, the Vertical-force changes are similar in character to those of the Declination; they are, however, in some cases reversed in the Horizontal force instrument.

The periods which elapsed between the time of origin of each movement and

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* See page 69.

its indication at each observatory have been tabulated and then divided by the distance measured on a great circle between the stations and Krakatoa.

These give a series of values for the velocity of transmission of the disturbances in miles per hour which form Table IV., showing the mean rate derived from the four salient points observed.

TABLE IV.

Mean hourly rate in English Miles of Transmission of Disturbance Wave from Krakatoa to the undermentioned Observatories.

Station.	Computed Distances from Krakatoa.	Recorded by Declinometer.	Recorded on Horizontal Force curve.	Recorded on Vertical Force curve.	True Means.
	English Miles.	English Miles.	English Miles.	English Miles.	English Miles.
Zi-Ka-Wei	2,792	1,012	1,212	1,355	1,193
Colába	2,815	729	1,105	1,090	997
Mauritius	3,353	751	—	761	756
Pawlowsk	6,074	812	945	997	918
Vienna	6,499	700	786	814	762
Kew	7,230	680	708	788	725
Stonyhurst	7,290	678	—	—	678
Lisbon	7,806	674	690	657	667
True Means	..	761	939	927	868

The values afforded by the different phases do not accord very closely; but a comparison of the curve of the Declinometer (Plate XL.) with that of the Kew undisturbed curve of its mean diurnal range, will show what a small effect the disturbing force had upon western instruments; and hence the difficulty in assigning exact points for measurement.

There is to be found in no curve, save that of Mauritius, actual magnetic peaks or hollows such as usually provide good measuring data, and this very feature was remarked upon by Captain Capello in his letter of October 29th, 1883. (*See* Appendix I.)

Nor are the various phases of maximum and minimum the same in the three elements; but the comparisons given in Table V. show that velocities fairly agree at each station; but they are still too irregular to enable us to state definitely whether the rate of travel of the magnetic waves was a constant, or a variable one. One feature well marked in the Tables is, that the motion eastwards between Sunda Strait and Zi-Ka-Wei was much more rapid than it was in the opposite direction between Krakatoa and Colába or Mauritius.

TABLE V.

Rate of Transmission in English miles of the Different Phases of the Magnetic Disturbance Waves, as Computed from Calculated Times of Origin. (Table IIIa.)

Between Krakatoa and	Phase I.				Phase II.				Phase III.				Phase IV.			
	Declination.	Horizontal Force.	Vertical Force.	Mean.	Declination.	Horizontal Force.	Vertical Force.	Mean.	Declination.	Horizontal Force.	Vertical Force.	Mean.	Declination.	Horizontal Force.	Vertical Force.	Mean.
	Miles per hour.	Miles per hour.	Miles per hour.	Miles per hour.	Miles per hour.	Miles per hour.	Miles per hour.	Miles per hour.	Miles per hour.	Miles per hour.	Miles per hour.	Miles per hour.	Miles per hour.	Miles per hour.	Miles per hour.	Miles per hour.
Zi-Ka-Wei ..	1,088	1,054	1,250	1,131	1,102	1,102	1,241	1,148	1,140	1,081	1,432	1,218	716	1,611	1,496	1,274
Colába.. ..	747	871	871	830	804	880	954	879	637	1,076	1,090	934	..	1,593	1,444	1,519
Mauritius ..	798	..	792	795	713	..	701	707	701	..	726	714	792	..	825	809
Pawlowsk ..	803	1,075	925	934	838	1,059	895	931	844	825	1,007	892	761	821	1,161	914
Vienna ..	694	789	..	742	722	747	777	749	715	793	835	781	668	814	831	771
Kew	692	679	756	709	709	697	756	721	692	739	803	745	625	718	836	726
Stonyhurst..	690	..	..	690	715	..	..	715	681	..	..	681	626	..	..	626
Lisbon.. ..	..	690	695	693	..	..	667	667	692	..	619	656	656	..	647	652
Pará	626	..	..	626												

The values for the declination are strengthened by the addition of Stonyhurst, and a fragment of a curve from Pará (Brazil); great uncertainty, however, attaches to the latter, as it is based simply upon a few eye observations.

Turning now to the mean results, we find that the average rate of travel of the magnetic movement on August 27th, 1883, was given by the various curves of magnetic disturbance at the observatories as follows :—

	Miles per hour.
For Declination	761
,, Horizontal force	939
,, Vertical ,, ...	927
Final true mean	868

The value obtained for the Declination wave closely accords with the value of the rate of travel of sound in air, as given by General Strachey,* but that given by the forces differs widely.

Owing to the great uncertainty attached to the identification of the disturbed points in the curves, and the scantiness of the material at our disposal, we have not been able to carry the discussion of the progress of the movement through any period subsequent to August 27th. Nor have we been able to find in the traces from any observatory, such abrupt non-magnetic oscillations as have been registered by magnetographs in this and other countries on the occasion of recent earthquakes.

Atmospheric Electricity.

The information to hand as to atmospheric electricity is confined to the abstracts from communications to 'Nature,' by Professor Michie Smith, of Madras, who gives certain isolated observations, but without sufficient data as to the conditions of atmospheric electricity at his station on other dates and at ordinary times to enable us to judge whether the phenomena he observed were exceptional or not.

Looking at the rapid and frequent variations of atmospheric electricity, as constantly recorded at Kew, Greenwich, and other observatories provided with continuously recording electrographs, we are of opinion that the material is totally unreliable for the purpose of deciding as to the influence or otherwise of the explosion in producing the effects attributed to it by Professor Michie Smith.

Neither at Kew nor at Greenwich were the electrical phenomena on August 27th, or subsequent dates, such as to call for special remark.

The papers on observations of atmospheric electricity contributed by Professor Michie Smith to the Royal Society of Edinburgh have not yet appeared in print, and therefore we have not been able to consult them.

G. M. WHIPPLE.

Kew Observatory,
March, 1887.

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* 'Proc. Roy. Soc.,' vol. xxxvi., p. 149.

APPENDIX I.

Extracts from Royal Society Krakatoa Committee's Correspondence. —Magnetic Disturbances.

C. Meldrum, Mauritius. January 26th, 1884.

"In the interval between the 26th and 30th of August last, magnetical disturbances occurred here, and I forwarded copies of magnetograms."

May 13th, 1884.

"I also sent you [Mr. Scott] our declination curve for September 16th, showing a usual magnetic storm, that you might compare it with the magnetic disturbances the 27th of August."

F. Chambers, Bombay. January 10th, 1884.

"The instruments do not appear to exhibit any corresponding disturbances."

J. Poortman, Batavia. January 8th, 1884.

"The photographic papers of the magnetograph from September, 1882, to September 1883, have been sent to him (Dr. Van der Stok) in order to compare them with those in Utrecht and with the magnetical observations made by the Dutch Circumpolar Expedition. During the rain of ashes on the 27th of August the curves were very much disturbed."

Rev. Marc Dechevrens, Zi-Ka-Wei. January 1st, 1884.

"Je ne sais si les irregularités magnétiques que j'envoie ont eu aussi une relation avec le bouleversement de Krakatoa; les magnétogrammes ne montrent rien le 28."

Robert L. J. Ellery, Melbourne. January 16th, 1884.

"Our magnets were not sensibly disturbed, nor did we note anything abnormal, except the barometric curve."

Rev. S. J. Perry, Stonyhurst. October 18th, 1883.

"The 27th was a little disturbed, but there was nothing of much note on the dates mentioned."

Captain J. de Brito Capello, Lisbon. October 29th, 1883.

"Les courbes des magnétographes exhibent aussi des perturbations hors du commun entre 11h. a.m. et 5h. p.m. de 27 et 29. Je dis perturbations hors du commun, car elles ne sont pas accompaniées des *peaks et hollows* de l'habitude."

C. Carpmael, Toronto. November 9th, 1883.

"The three magnetograph traces were unusually steady, in fact, so much so was this the case, that in the 'Monthly Weather Review' for August a remark* is made as to the exceptional steadiness of these curves."

M. Hooreman, Brussels. November 27th, 1883.

"Les autres enregistreurs, du magnétisme et de l'électricité entre autres, n'ont rien revélé de particulier dans les journées du 26 au 30."

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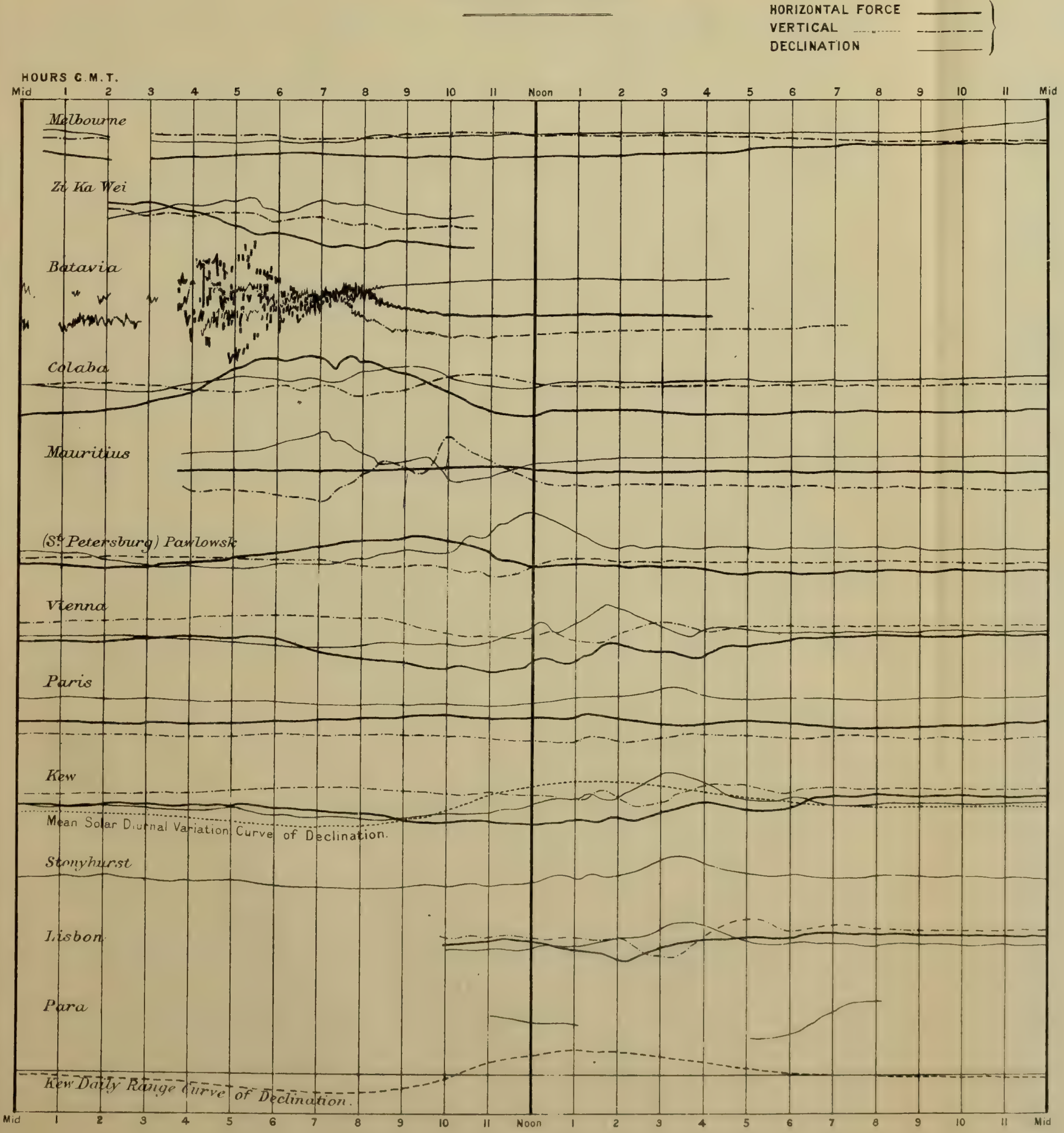
* "The remainder (after the 22nd) of the month was entirely free from any disturbing element; this of late has been an unusual feature in the month's curves, viz., seven consecutive days being calm."

COPIES OF TRACES PRODUCED BY MAGNETOGRAPHS AT THE TIME OF THE KRAKATOA EXPLOSION AUGUST 27TH 1883.



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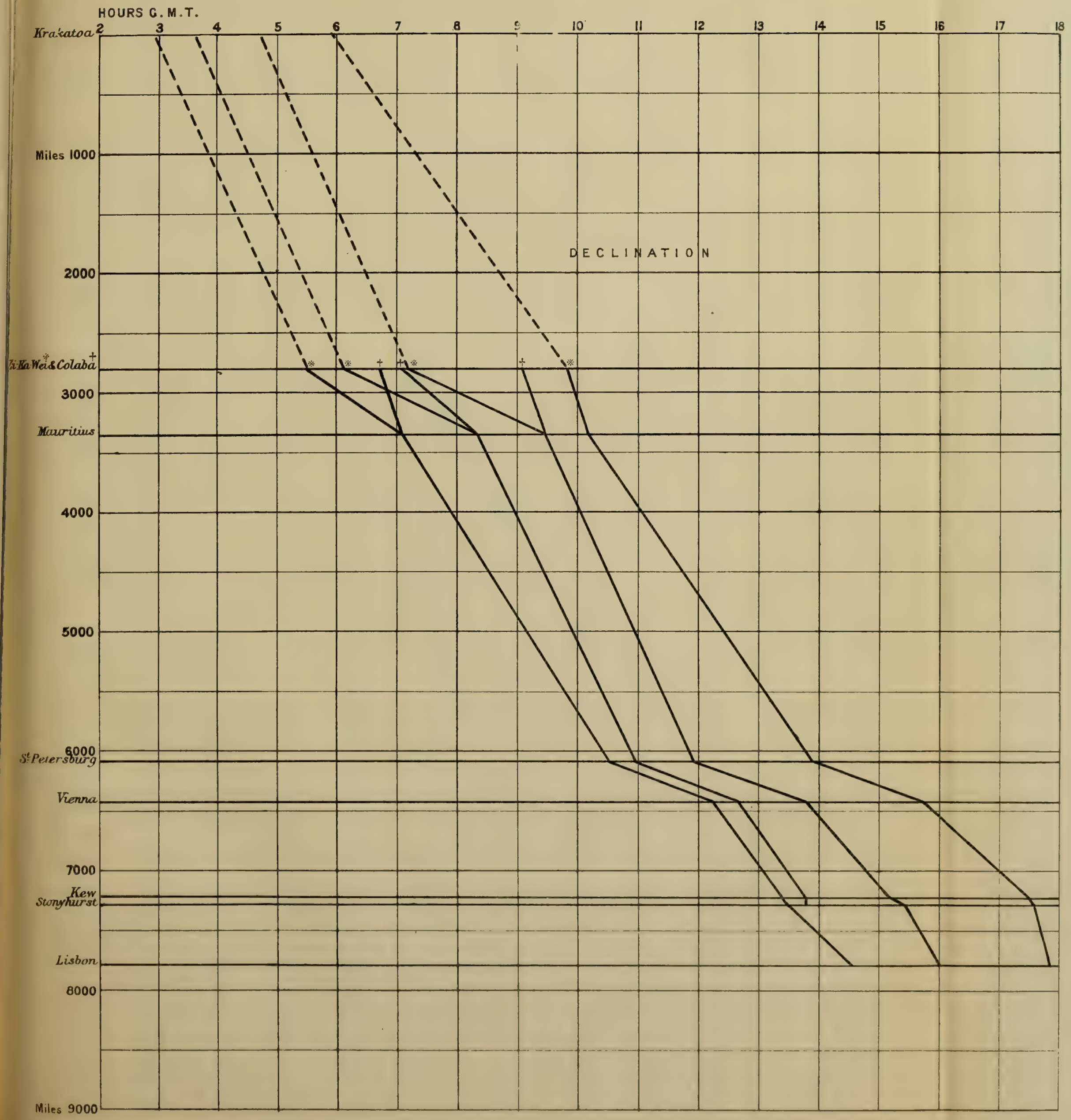
KRAKATOA MAGNETIC DISTURBANCE



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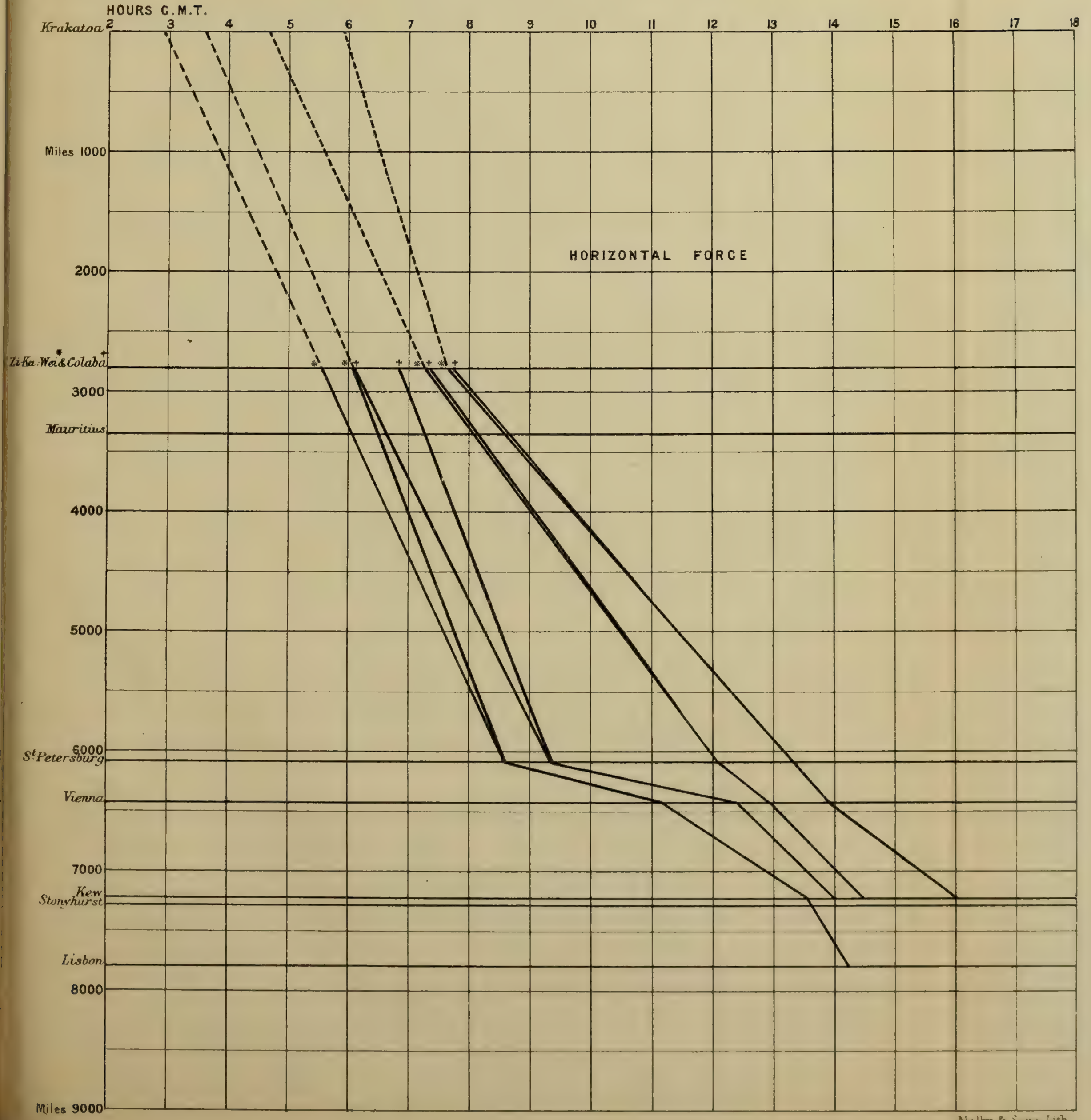

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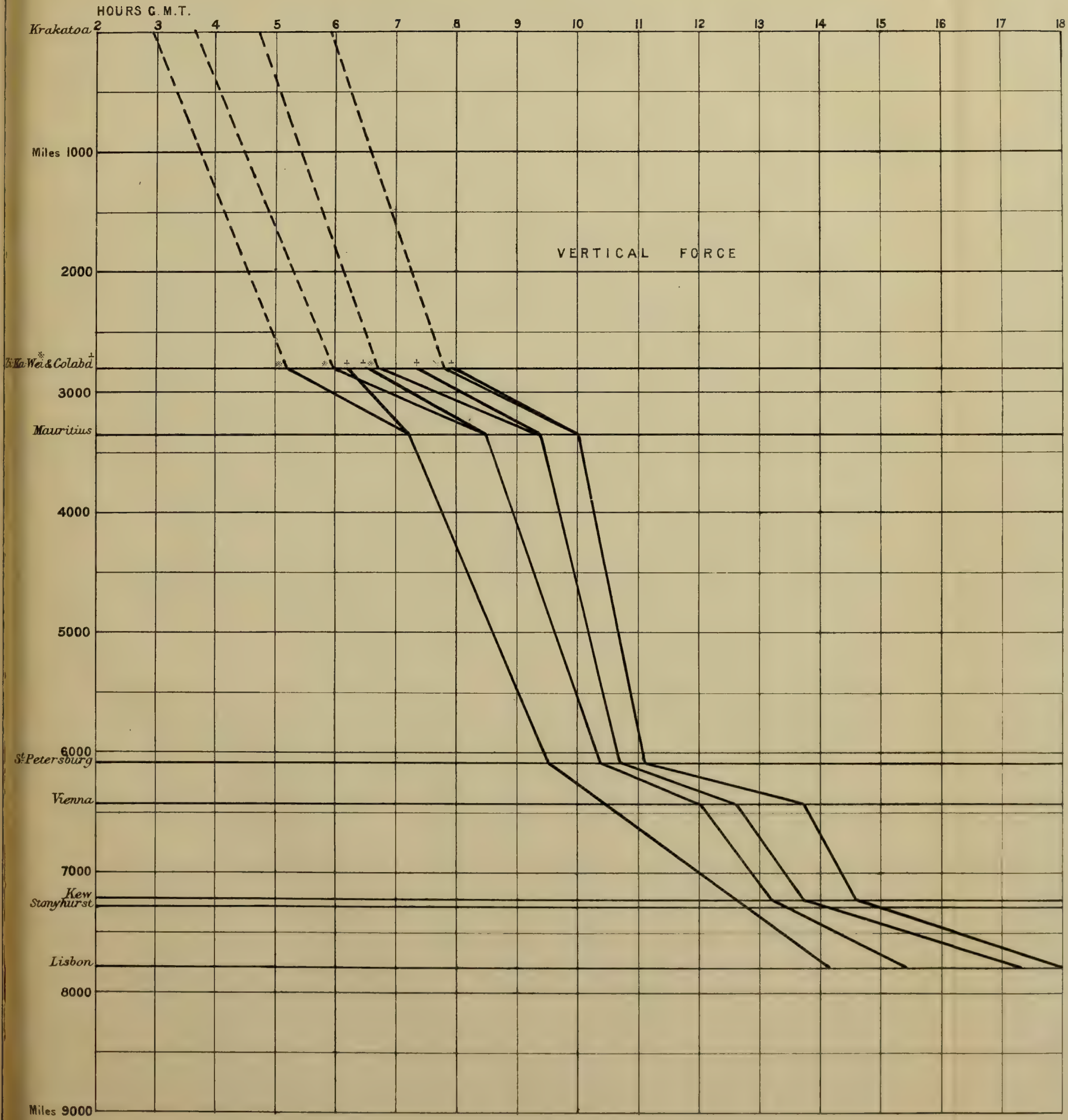

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APPENDIX II.

Extracts from a Letter to Mr. WHIPPLE *from Dr.* VAN DER STOK, *Director of the Batavia Observatory.*

January 26th, 1884.

"On Sunday afternoon I took a seat before a Declinometer on which 10 seconds of arc were easily read off, and I saw only a very quick vertical oscillation, no horizontal motion at all."

"All these noises had no effect on the magnets and no magnetic disturbance was observed. Now, I mean by disturbance, an earth-magnetic disturbance. In the morning, however, at six o'clock, an almost imperceptible shower of light ashes began to fall, and at the same time the curves showed oscillations of a character totally different [from] a common disturbance."

"The mean value was not altered much for a long time, as usual, but the oscillation took place in rather quick periods, not too quick, however, for photographic registration."

"The reason of this kind of disturbance was evidently the magnetic iron contained in the ashes; the disturbance came to an end at the same time as the shower-fall."—"I never stated [that there was] other than purely mechanical [movement] of an earthquake in the magnets."

Under date January 21st, 1886, Dr. E. VAN RIJCKEVORSEL, of Rotterdam, wrote to Mr. WHIPPLE:—"Does it interest you to know that my assistant, occupied at that time with the variation instruments at Pará, found his only disturbance worth speaking of on the day of the [Krakatoa] eruption."

INDEX OF PLACES MENTIONED IN THE REPORT.

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* V. is used throughout to indicate Volcano.

INDEX OF PERSONS MENTIONED IN THE REPORT.

INDEX OF SHIPS MENTIONED IN THE REPORT.

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