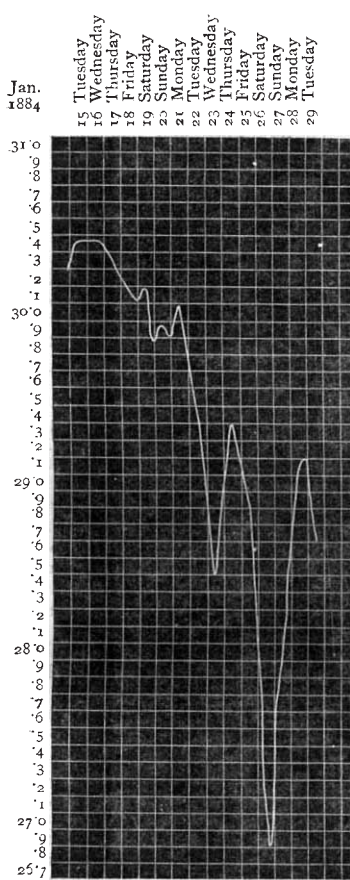


bright and clear and distinctly iridescent. Around the head of the figure was a beautiful halo of light, and from the figure itself shot rays of colour normal to the body. The sight startled me more than I can now tell. I threw up my hands in astonishment, and perhaps some little fear, and at this moment the spectre seemed to move towards me. In a few moments I got over my fright, and then, after the figure had faded away, I recognised the fact that I had enjoyed one of the most wonderful phenomena of nature. Since then we have seen it once or twice from Jeff Davis Peak, but it never created such an impression upon me as it did that evening when I was doing service as a heliotroper all alone on the top of Arc Dome."

#### The Storm of January 26

DURING this storm there was a remarkable depression of the barometer, it falling to 26.9, as shown in the accompanying chart. The lowest depression last year was 28.2 on Nov. 25. Lurgybrack lies in lat. 54° 56' N., and long. 7° 42' W. It is 225 feet above the Ordnance datum level. A nearly similar depres-



sion was observed at Letterkenny, 140 feet above the Ordnance datum level. The wind veered round from the north west by north and east to the south, and from the latter by west to north. The storm was succeeded by a fall of snow, which has now melted away.

G. HENRY KINAHAN

Lurgybrack, Letterkenny, Ireland, January 29

#### EARTHQUAKE DISTURBANCES OF THE TIDES ON THE COASTS OF INDIA

FOR some years past tidal stations have been established at various points on the coasts of India, from Kurrachee round *via* Cape Comorin and Adam's Straits to Calcutta, and on to Rangoon and Moulmein; also beyond these points, eastwards at Port Blair in the

Andaman Islands, and westwards at Aden; but not anywhere in the Island of Ceylon, which happens—unfortunately for the interests of science—to be outside the administration of the Government of India. At each of the tidal stations an observatory has been established, containing a self-registering tide-gauge, and all requisite meteorological instruments, with a clerk in charge who tends the instruments, sets the driving clocks to true time—usually received telegraphically from Madras—and sends in daily reports to the supervising officer. That officer exercises a general superintendence over all the tidal stations, inspects them periodically, collates and analyses the observations, and deduces from them the values of the “tidal constants” for each port or point of observation; these constants enable future tides to be predicted, and tide tables to be prepared for the guidance of mariners; they are also otherwise valuable, in that they have thrown light on the question of the earth’s rigidity, and on various other matters of scientific interest.

The operations have been carried on in connection with the Great Trigonometrical branch of the Survey of India. Major A. W. Baird, R.E., has been the supervising officer from their commencement in 1873 up to the present time, with the exception of an interval of a little more than a year, when he was on furlough in Europe, and Capt. J. Hill, R.E., first, and afterwards Major M. W. Rogers, R.E., officiated for him.

At certain of the Indian stations the registrations have twice indicated that the normal tides had been greatly disturbed by supertidal waves: first, on the occasion of the earthquake in the Bay of Bengal on December 31, 1881; and secondly, during the volcanic eruptions in the Island of Krakatoa, between Sumatra and Java, which occurred on August 27 and 28 last. The first disturbances do not appear as yet to have attracted much attention out of India; a full account of them is given in the General Report on the Operations of the Survey of India for 1881-82, and also in the *Proceedings of the Asiatic Society of Bengal* for March 1883. The second are now famous all the world over, not merely because of the havoc they are known to have produced on the spot and at the time, but also because of the effects they are believed to have produced on the condition of the atmosphere long afterwards and in far distant quarters of the globe. A report on the tidal disturbances at Indian stations which were caused by the eruptions at Krakatoa has been drawn up by Major Baird, and sent to me for communication to the Royal Society, and an abstract of it was read at the meeting of the Society on January 31.

I now propose to indicate certain points of similarity and others of dissimilarity between the recorded effects of the disturbing forces on the two occasions; for fuller details the reports themselves must be referred to.

The usual effect of an earthquake or volcanic eruption occurring at an island or under the bed of the sea is the transmission in all directions of an “earth-wave” and a “sea-wave”; the former travels with much greater rapidity than the latter, and may reach points which the latter does not reach; or it may die away and cease at points far short of those attained by the latter; which of the two will travel the greater distance depends generally on the structure and homogeneity of the strata through which the earth-wave is transmitted, and on the depth of water and configuration of the bottom over which the sea-wave passes.

On the occasion of the earthquake of December 31, 1881, the “centre of impulse” was situated under the bed of the ocean in the western portion of the Bay of Bengal; the shock of the earth-wave was very violent in the Andaman and Nicobar Islands, and along the entire length of the Madras coast up to Calcutta, and also far inland; it was followed by a succession of sea-waves which the tidal diagrams show to have arrived after the

earth-wave, at an interval ranging from half an hour at Port Blair (in the Andamans), the nearest station, to six hours at Dublat (in Sangor Island at the mouth of the River Hooghly), the furthest station at which such waves were certainly registered. At Rangoon, Moulmein, and various points in the Mergui Archipelago, the earth-wave was distinctly perceptible, though its shock was here much less violent; but no trace of a sea-wave has been met with at any of the tidal stations in this quarter; the belt of islands and shoals which extends from Cape Negrais to the Island of Sumatra, practically dividing the Bay of Bengal into two portions, must have formed a barrier to the sea-waves, for though great and numerous at Port Blair, they died away in the deep sea beyond, and in no case reached the eastern coast line.

The position of the earthquake in the Bay of Bengal was necessarily not a matter of observation as at Krakatoa; but it has been inferred by Major Rogers from the following facts. The moment at which the shock of the earth-wave was felt happens to have been recorded with considerable accuracy at three places, two on the west coast of the Bay, viz. the Madras Astronomical Observatory and the tidal station at False Point; the third on the east coast, Kisseraing, a principal station of the Great Trigonometrical Survey, where Major Rogers was actually at the moment observing a distant station in the field of the telescope of his theodolite. He reports that "he saw the earthquake before feeling it," for he first became sensible of its occurrence by noticing the object which he was observing appear to rise and fall in the telescope; he immediately examined the spirit-levels of his instrument, found they were violently agitated, and made a note of the time. Subsequently he ascertained that the shock he felt and those recorded at Madras and False Point must have occurred almost simultaneously, due allowance being made for the differences of longitude. Therefore, assuming the earth-wave to have travelled from the centre of impulse with the same velocity in all directions, the centre would be near that of the triangle joining the three points of observation, but probably a little to the south, towards the line joining Port Blair and Negapatam, the stations at which the tidal disturbances were the greatest.

Having thus ascertained the probable position of the centre of impulse, Major Rogers proceeded to ascertain the probable time of the earthquake. Here again he was favoured by his facts. It so happened that his assistant, Mr. Rendell, had just completed an inspection of the tidal station at False Point, and was at work on a line of levels a few miles away, when he felt a violent shock of earthquake; he noted the time; the clerk at the station also felt the earthquake, and noted that the observatory was much shaken; afterwards it was found that at the time recorded by Mr. Rendell the pencil of the tide-gauge had been vibrating very sensibly on the diagram; the vibration must have been caused either by the shaking of the observatory, or by a forced sea-wave such as is sometimes produced momentarily in shallow waters by a passing earth-wave. The great sea-wave which was transmitted from the centre of impulse arrived 3 hours 18 minutes afterwards. Now there can be no question that the vibration mark on the diagram correctly registers the moment at which the earth-wave reached False Point; Major Rogers therefore conjectures, with much probability, that a similar very prominent vibration mark on the Port Blair diagram registers the moment of the arrival of the earth-wave at Port Blair; thirteen minutes after the time thus registered Major Rogers felt the earthquake at Kisseraing, and as the distance between the two points is 400 miles it may be inferred that the earth-wave travelled with a velocity of about 1800 miles an hour. With this velocity, the distance of the assumed centre of impulse from either of the three surrounding stations,

and the time of the occurrence of the earth-wave at either station, Major Rogers calculates the time of the original disturbance when both the earth-wave and the sea wave were initiated. Comparing this time with that of the arrival of the sea-wave at his stations, he obtains the following velocities for the sea-wave: to Port Blair 360 miles an hour, to Madras and Negapatam 240, to False Point 180, and to Dublat 120. The average depth of the sea is known to diminish in every instance of diminished velocity.

The sea-wave here specifically referred to was the first and generally the greatest of the supertidal waves; its amplitude from trough to crest was a maximum, 36 inches, at Negapatam, and 30 inches at Port Blair; it was always positive, the crest preceding the trough and raising the sea-level. The latter point is to be specially noticed because the first result of the great eruption at Krakatoa was the reverse of this, namely, a negative wave or general lowering of the sea-level at the stations of observation, as will be shown more fully further on. Secondary sea-waves followed the first, disturbing the normal tides for some hours; their greatest duration was twenty-five hours at Port Blair, the nearest tidal station to the centre of impulse. A single earth-wave of a few seconds' duration is all that appears to have been perceived at the tidal stations; possibly, therefore, the whole of the tidal disturbances were due to a single earthquake.

Proceeding now to the eruptions at Krakatoa, we find that while there is no uncertainty as regards their locality, and there is evidence of one great eruption far exceeding all the others in violence, there is as yet no certain information of their number nor of the times at which any of them, even the greatest, occurred. No earth-waves appear to have reached India; but sea-waves of more or less magnitude were transmitted to all the tidal stations on both coasts of the peninsula, and not alone to those on the east coast, as on the former occasion; they were also transmitted far beyond, to Aden, the Mauritius, and the south-east coast of Africa, as shown in Major Baird's report. Lately it has been announced that traces of the sea-waves have been discovered at French tidal stations on both coasts of the Atlantic.

The principal facts set forth by Major Baird are the following:—

1. Distinct evidence of tidal disturbance was met with at twelve of the seventeen Indian tidal stations, including all which were fairly placed to receive the force of the impulse from Krakatoa; but, as in the previous instance, no disturbance was perceived at the stations on the east coast of the Bay of Bengal.

2. The first result of the great eruption at Krakatoa was a negative supertidal wave, or general fall of the sea-level, at Major Baird's stations and also at the Mauritius.

3. This negative wave was succeeded by a great positive wave, at an interval ranging from seventy-five minutes at Negapatam, the station nearest Krakatoa, to twenty-four minutes at Aden, the most distant station.

4. Supertidal waves of greater or less magnitude were registered at the Indian stations some hours before the negative wave of the great eruption, showing that there must have been antecedent minor eruptions. They appear at Aden about three hours before the negative wave, and eighteen hours before at Negapatam, showing that the explosions were at first comparatively feeble, affecting only the nearer stations; but afterwards they increased in intensity and became sensible even at Aden, a distance of over 4000 miles.

5. Waves of amplitudes ranging from a maximum of 22 inches at Negapatam to a maximum of 9 inches at Aden were registered at all the more favourably situated stations. The first was the positive wave immediately succeeding the primary negative wave, and it was generally of a greater amplitude than any other wave, but in a



few instances it was succeeded by greater waves. The succeeding waves maintained considerable amplitudes—not less than half the maxima values—for about twelve hours, appearing at intervals of one or two hours apart at all the more prominent stations. They were succeeded by wavelets gradually diminishing in size, but continuing for some time, being traceable on the diagrams for August 29 and 30, the second and third days after the great eruption. It is noticeable that they ceased first at Port Blair and Negapatam, the two nearest stations, and last at Aden, the farthest station.

6. Loud reports, resembling the firing of distant guns, were heard at Port Blair on August 26 and 27, and being supposed to be signals from a vessel in distress a steamer was sent out in search of the vessel; similar reports were heard on the 26th in Ceylon.

These facts show that the great eruption at Krakatoa was preceded by minor eruptions sufficiently powerful to produce effects which were sensible at a distance of upwards of 4000 miles; also that it was probably followed by minor eruptions, to the influence of which the long-protracted continuance of tidal disturbance is due.

The time at which the great eruption occurred is still not known with any precision. Major Baird has endeavoured to calculate it from the following data: he was informed by Her Majesty's Consul in Java that the first great (positive) wave reached Batavia at 12h. 10m. local time on the afternoon of August 27; as the distance from Krakatoa by sea is 105 miles, and the average depth of the sea about 186 feet, he infers from the table of the velocity of free tide waves passing over seas of different depths, in Sir George Airy's article on "Tides and Waves" in the *Encyclopedia Metropolitana*, that the wave must have taken about two hours to reach Batavia, and therefore that it must have started at 10.5 a.m. Krakatoa time, allowing five minutes for the difference of longitude. Another estimate has been recently furnished by General Strachey in a paper—read before the Royal Society—on the "Barometrical Disturbances which passed over Europe between August 27 and 31"; General Strachey connects these disturbances with the great eruption at Krakatoa, and infers, from the recorded evidence of the times of transit of the barometric waves over the European observatories, that the initial barometric rise occurred at 9h. 24m. Krakatoa time on the morning of August 27. Now we have seen that the first effect of the great eruption on the ocean was the production of a negative wave which preceded the great positive wave by an interval of seventy-five minutes at Negapatam, and twenty-four minutes at Aden; if then we assume that the interval was somewhat more than seventy-five minutes at Krakatoa itself—as is to be inferred from the fact that wherever registered it increases as the distance from the centre of impulse diminishes—General Strachey's and Major Baird's determinations will be seen to corroborate each other very closely; indeed, considering the absolute independence of the two methods of deduction, the facts of observation being in one instance derived from the atmosphere, in the other from the ocean, the coincidence between the results is very striking.

Major Baird has calculated the velocities with which the great positive wave travelled from Krakatoa to the more important of his own stations, and also to Port Louis in the Mauritius, and Port Elizabeth in South Africa.<sup>1</sup> Starting with the assumption that the wave left Krakatoa at 10.5 a.m., August 27, local time, he finds that it attained its maximum value, 467 statute miles per hour, in transit to both Port Louis and Port Elizabeth. Considerable interest attaches to this determination, in that it is identical with Sir George Airy's tabulated value of the velocity of a free tide-wave passing over an ocean 15,000 feet deep, which is supposed to be the average depth of the

ocean in this direction; moreover, the fact that the same velocity is obtained for both the ports, and that the nearer of the two is only 3400 miles from Krakatoa, while the other port is 5450 miles distant, indicates that there is probably no material error in Major Baird's adopted time of starting. The velocity of the wave in all other directions is less, viz. to Galle 397 miles, to Negapatam 355 miles, and to Aden 371 miles. The velocities are necessarily computed on the assumption of a uniform rate of progress from the origin to the point reached; but each of the slower waves must have coincided with the wave which impinged on Ports Louis and Elizabeth for a considerable distance in the early portion of its course, and it must then have travelled with the same high velocity; afterwards, on passing over shallower seas, the velocity must have much diminished, and very possibly it may have fallen to the smaller velocity values which Major Rogers has calculated for the sea-waves in the Bay of Bengal, on the occurrence of the earthquake of December 31, 1881.

The Admiralty chart of the Eastern Archipelago shows that Krakatoa is situated at the focus of what may be regarded as a parabolic figure, formed by the contiguous portions of the coasts of Java and Sumatra; the axis of the figure is directed towards the Indian Ocean. Thus the waves generated by an eruption at Krakatoa would be mostly propelled towards that ocean, both directly and by reflection from the coasts; but near the apex of the parabola there is an opening, the Straits of Sunda, through which a great wave passed, carrying widespread destruction for some distance beyond along the contiguous coasts. This wave may have impinged with great force on the south-west corner of the Island of Borneo, which is on the prolongation of a straight line drawn from Krakatoa through the Straits. But it did not reach Singapore, where a tide-gauge is established, and which is within a third of the distance of the nearest Indian station from Krakatoa; the Master-Attendant at Singapore reports that the gauge shows "no difference whatever in the tide." This is obviously due to the fact that the wave which passed through the Straits of Sunda had but a shallow sea to advance over towards Singapore, and its course must have been greatly impeded by numerous islands and shoals and the narrow straits and passages between them. For similar reasons, and because the axis of the parabola in which Krakatoa is situated is pointed towards the Indian Ocean, it is probable that the effects of the eruptions were not conveyed to anything like so great a distance along the numerous groups of islands to the east and into the Pacific Ocean.

J. T. WALKER

#### THE INDIAN SURVEY<sup>1</sup>

THIS is the fifth report of the amalgamated Department of Surveys under the Government of India. It is divided into two parts with an appendix. Part I. gives a summary of the operations of the great trigonometrical, the topographical, and revenue survey parties; also of the geographical, geodetic, and tidal, and levelling operations. Part II. describes the operations at the Head-Quarters Offices, viz. the Surveyor-General's Office, the Revenue Survey Office, the Lithographic Office, the Photographic Office, and the Mathematical Instrument Department, all in Calcutta; and of the Trigonometrical Survey Office in Dehra Dun. Index charts, coloured maps, and sketches showing the present state of this very important department accompany this report; to which is prefixed, as frontispiece, a "Specimen of *Heliogravure* by Major Waterhouse's Process," which invites the

<sup>1</sup> "General Report on the Operations of the Survey of India during the year 1881-82." Prepared under the superintendence of Lieut.-General J. T. Walker, C.B., R.E., F.R.S., &c., Surveyor-General of India. (Calcutta, 1883.)

<sup>1</sup> For these ports he employs the data published in NATURE, vol. xxviii. p. 626.