EARTHQUAKES IN CONNECTION WITH ELECTRIC AND MAGNETIC PHENOMENA.

By John Milne.

[Read March 7th, 1890.]

The only paper which has hitherto been brought to the notice of the Seismological Society of Japan treating of the relationship of earthquakes, earth currents, and magnetic phenomena is the contribution by Professor R. Shida on "Earth Currents" (Trans. Seis. Soc., Vol. IX., Pt. 1.). In the following pages Professor Shida's examples have been amplified, and to them many instances where electrical and magnetical phenomena have accompanied volcanic or seismic disturbances have been added. The object of this paper is to draw attention to a variety of observations which require extension, and to express the hope that the systematic study of such observations may lead to the explanation of several phenomena which at present are not understood.

Examples of Electric Phenomena.

From the observations on the lightning flashes playing in and round the column of ashes which accompany volcanic outbursts, and from the different investigations of Palmieri upon the slopes of Vesuvius, we know that at the time of a volcanic eruption the atmosphere becomes highly charged with electricity. One explanation for these phenomena is that the high pressure steam escaping from the crater is playing the part of the steam in a hydro-electric machine, the action being intensified by the friction of the heated solid particles against each other during their repeated ejection. These observations suggest that there may possibly be some connection between earthquakes and resultant electrical phenomena. At the time of earthquakes it has often happened that the air has been found to be in a very electric state. For example, during the earthquake of 1808 in Piedmont, Fuchs tells us that such a condition was observed.

Humbolt observed that during the earthquake of Cumana the electroscope quickly showed the presence of electricity in the atmosphere.

A belief in South America is that electric discharges in the atmosphere and earthquakes are in inverse proportion to each other. The Mississippi and Ohio earthquakes of 1812 are said to have corroborated such an opinion.

Luminous appearances in the heavens are often mentioned in the records of earthquakes, as for instance at the time of the Lisbon earthquake in 1755 and that of Catania in 1693. In 1805 at Naples fire balls were observed about the time of the first shock. As seen from the sea, clear rays of light appeared to discharge themselves from the tops of the highest houses. These appearances, which are usually considered as electrical phenomena, are extremely numerous in the records of earthquakes. Just before the earthquake of New England in 1727 flashes of lightning were seen [Phil. Trans. XXXIX.]. Again before the earthquake in Sicilia (January 11th, 1692-3) a great light like a fire is said to have been observed in the sky [Phil. Trans. XVIII.].

A letter from Mr. Thomas Henry, F.R.S., describing the earthquake felt at Manchester (14th September, 1777) speaks of his wife and others receiving in various parts of their bodies shocks similar to electrical shocks.

Subsequent to the shock many people complained of nervous pains and hysteric affections similar to those who have been strongly electrified. Perhaps fright might have contributed to produce some of these effects [Phil. Trans. LXVIII. p. 221].

Schmidt says the maximum frequency of electric phenomena occurs in the middle of October or a few days later, and the minimum about the first week in March. If we refer to Schmidt's conclusion respecting the periodicity of earthquakes we shall see, as he points out, that the maximum of earthquakes and the electric storms occur at periods but little different.

To put the matter more generally we find the greatest intensity of atmosphere electricity in winter, which is the season when earthquakes are most frequent.

Earthquakes and Earth Currents.

Attention was drawn to the connection between earthquakes and earth currents by Professor W. E. Ayrton in a communication to the Asiatic Society of Bengal in June, 1871, who observed that the Indian earthquake of December 15th, 1872, was preceeded by such strong earth currents on the previous evening in the land lines from Valentia to London, that in order to send messages it was necessary to loop the lines and in this way cause the current of one line to neutralize the other [Asiatic Society of Japan, April 25th, 1877].

The Egyptian earthquake (January 12th, 1873) was also preceeded by strong earth currents. The Italian earthquake of March 17th, 1875, was accompanied by great disturbances in the land lines.

Again in 1871, a few minutes before and after the earthquake of March 17th, positive electrical currents were rushing towards England through the Anglo-American cables, which were broken near Trinity Bay, Newfoundland [C. F. Varley, *Nature*, 1871, April 20th; also *Am. Jour. Sci.* I. 1871, p. 472].

As another example it may be mentioned that the earthquake of Ischia (1881) was signalled along some of the Mediterranean cables.

A remarkable example of the connection between earthquakes and the development of earth currents are the observations of M. Destieux, Chief of the Telegraph Bureau of Fort de France in Martinique, at the time of the earthquakes of September, 1875. Not only were the lines so strongly charged that they gave shocks to the hand, but the electric disturbances as indicated by the needle of a galvanometer in all cases seem to have preceded the shock by considerable intervals. Thus on September 17th the galvanometer was greatly disturbed, at 10.25 a.m., and at 10.52 there was a violent shock. At 12.19 the galvanometer was again disturbed. At 2.45 the electric disturbances were repeated, and at 3 p.m. came a strong shock. At 4 p.m. the disturbances were very great and at 6 o'clock came another shock. Similar observations were made on the succeeding day. [Compte Rendus, LXXX., 1875, p. 693].

The results of some observations on this interesting subject, made by F. P. Crescimano, at Corleone, in Sicily, in 1876, were as follow:—

Two galvanometers were taken, and one was placed in a telegraphic circuit whilst the other was placed in a circuit one pole of which led to a well and the other to a hole in the ground. At the time of several small shocks the first of these instruments gave no indications. The well galvanometer gave some feeble movements indicating what was probably a positive current. Subsequently some strong shocks caused deviations of 8°. On July 9th, 1876, at 8.35 p.m. a shock occurred during the time that a despatch was being sent to Palermo. This was stopped and the signal "Earthquake! Earthquake! Earthquake!" was sent. The operator, not understanding the signal, replied "Lift up the *tasto*, the current is too strong." This was raised, but the current was still too strong. The Palermo line was then thrown out of circuit and the Prizzi line put in. The galvanometer oscillated for 7 seconds and came to rest after 15 seconds. During the time that the Palermo line had been in circuit the needle of the galvanometer had made slight oscillations. A few minutes before the shock, the currents, which had previously been good, suddenly became bad. It is supposed that a positive current had suddenly struck the line. [Rossi. Meteorologia Endogena, I. p. 86-87].

Causes of Currents and Electrical Phenomena.

In 1873 P. Serpieri observed that in many instances needles of galvanometers had been deflected a short time before the occurrence of earthquakes and that deflections were due to negative earth currents. In the *Revista Scientifica* 1874, p. 165, he offers the suggestion that the negative nature of the earth current may be due to the sudden development of a large quantity of steam which is electrically positive—the steam being the cause of the earthquake. In this article he quotes the interesting observation of Professor Domenico Ragona, who found that at the time of an earthquake there was a current from the earth passing through a galvanometer and a lightening rod-like conductor to the atmosphere. To observe these currents, Professor Ragona suggests the use of a convenient apparatus, where the current passes by wire from the earth through a galvanometer to the flame of an oil or petroleum lamp, the base of which is isolated from the ground (L'Elettricita 1887, No. 16, p. 241).

In connection with the observations made upon earth currents *Der Naturforscher* VIII. p. 127, refers to the negative electricity of a hot spring in Baden, and in an article in *Jahrgung* XX. No. 27, p. 243, makes special reference to the work done by Professor Luvini of Turin in endeavouring to obtain the assistance of telegraph operators in observing unusual disturbances in their instruments especially at or about the time of earthquakes.

One cause possibly producing earth currents would be the inrush of steam into fissures and cavities produced in rocks at the time or previous to the resulting crash which might be the cause of an earthquake. In addition to this, deep down in the earth we may conceive of the existence of intense chemical action caused by heated steam or molten matter acting on each other and the materials they came in contact with giving rise to currents of considerable magnitude. The earth currents of an active volcano are a subject yet requiring investigation.

At the time I was observing the effects of artificial earthquake produced by the explosion of dynamite, I made the following experiments on earth currents:—

At distances of from 10 to 30 ft. from the source of the explosion an iron bar was planted firmly in the ground. This was connected by a wire with a second bar also in the ground about ¼ mile distant at the other side of a deep moat, at a place where the vibration resulting from the explosion could not be perceived by carefully watching the surface of a dish of mercury.

Near to this end of the circuit a Clark's differential galvanometers was introduced.

The results obtained were that prior to the sound of the explosion and prior to the observation of any tremor in the mercury there was a strong deflection (10 to 40°) of the galvanometer needle. The direction of this deflection was always the same. After deflection the needle of the galvanometer sometimes remained steady, sometimes however it very slowly (say in one hour) crept back to its normal position. When the first earth bar was moved to a point 150 feet distant from the explosion where the earth vibrations were feeble, no deflection of the needle was observed.

The probable explanation of this experiment is that in consequence of the mechanical motion of the earth bar at the end of the line, its electric state, due to moisture and oxidation owing to a change in its contact with the earth, was altered. Certainly similar effects could be produced by moving one of the bars or by hammering on the ground in its vicinity.

The earth currents observed at the time of earthquakes may therefore, perhaps, be explained as being due to mechanical disturbances in the earth plates.

So far as earth currents are concerned, when we consider the various manners in which they may be produced the only point to be wondered at is that they have not been observed more frequently.

To give an explanation of the electrical phenomena which have been observed in the air is more difficult. In some cases they may only have been atmospheric phenomena which have accidently synchronized in the time of their occurrence with earthquakes. Possibly perhaps sudden dislocations of strata may occasionally have caused sudden developments of statical electricity manifesting itself as luminous discharges in the air.

Earthquakes and Magnetic Phenomena.

On many occasions it has been observed that earthquakes have produced effects upon magnets or magnetic needles. In some cases the disturbances which have been noted may possibly have been due to mechanical action. About two hours before the destructive earthquake in 1855 the owner of a spectacle shop in Tokio observed that a magnet dropped some pieces of iron which had been attached to it. This observation led to the construction of a magnetic seismoscope described in a book called the *Ansei-Kembun-Roku*.

Experiments made by Professors Ayrton and Perry, to determine whether a magnet at the time of an earthquake changes in its magnetic intensity, so far they went, showed the idea to be unfounded.

In 1822 Arago and Biot made simultaneous observations of unusual movements in magnetometers at Paris which coincided with the occurrence of slight shocks in Switzerland and the South of France.

Humbolt on November 4th, 1799, observed that in the earthquake of Cumana, although the magnetic declination and intensity were unaltered the dip was diminished 48 minutes.

From this it subsequently slowly returned. The declination and the intensity of the earth's magnetism had, however, remained unchanged. [Mallet, Reports of British Association 1850]. In October 1802 the magnetic needle made at Lima 219 swings in 10 minutes, but after the earthquake only 213 swings. The inclination was also slightly altered,—before the disturbance being 9.59 degrees and after only 9.12 degrees.

Prof. M. S. de Rossi gives several interesting examples of the coincidence between magnetic disturbance and earthquakes.

On Nov. 1st, 1755, on the authority of Sarti, it is stated that all magnets let their weights fall. The same year Bertrand, observing at Morat near Neuchatel, says that at the moment of the earthquake the needle of a compass was seen to alter 25°, and on the same day at a place on the frontiers of Switzerland, some filings hanging from the point of a needle were observed to revolve against the needle; afterwards they returned to a vertical position.

In 1869 an earthquake was felt in Rome, and it was observed that many horse-shoe magnets dropped their armatures.

Count Malvasia made a long series of observations on a small magnet holding light pieces of iron similar to an apparatus constructed by Bertelli. From the table of these observations it seems that the piece of iron often fell, sometimes with shocks and sometimes without them.

Palmieri and Sacchi say that before the largest shocks at Melfi they observed changes in dip [Meteorologica Endogena Vol. I.].

The results obtained by Malvasia appear to be very similar to the results said to have been shown by the magnetic seismoscope invented in Tokio.

In the *Electrical World*, Nov. 30, 1889, we read that M. Mascart reports that M. Moureaux, who has charge of the magnetic observations at Saint Maur has informed him that the magnetic curves for Oct. 25 show indications of disturbances similar to those which have previously been noticed on the occasion of earthquakes, &c. Since this the papers have announced an earthquake which caused considerable destruction at Gallipoli, and which, from all accounts, seems to have taken place at the moment when the magnetic disturbances were observed at Saint Maur.

In this instance it would appear that the disturbance of the magnetic instruments could not be attributed to mechanical transmission of the shock.

As another example of coincidence in the occurrence of earthquakes and magnetic disturbance I give the following *précis* of a short article on Earthquakes, published in the Annual of the National University of Colombia, 1870, translated by Mr. T. H. Wheeler, of the British Legation at Bogota.

After shortly stating and discussing Fabel's? theory that earthquakes are caused by the action of the moon upon incandescent fluids in the interior of the earth, causing "seismic tides," the author mentions in contradiction to this theory, the fact, of which he presumes that Fabel was ignorant, that none of the South-American volcanoes throw out lava, but only calcined trachytic rocks, pumice stone, water, and enormous quantities of carbonic acid gas. These volcanos, therefore, cannot be fed from the same sources as those in Europe which eject lava, and the incandescent fluid existing in the interior of the earth cannot be one continuous mass: the tides caused by the action of the moon upon such fluids cannot therefore account for the production of earthquakes or of the eruptions of volcanoes.

The author then proceeds to discuss a theory of magnetic currents as a probable cause of certain forms of earthquakes.

During the earthquakes which occurred in Chile, Bolivia, Peru, and Ecuador, successively on the 13th, 14th, and 16th of August, 1868, a good declinometer placed on the top of a church in Quito, and constantly observed since the middle of June by a competent observer, indicated extraordinary deviations towards the East, the signs of strong magnetic tension. On the 15th, the eve of the catastrophy at Imbabura, it marked 4′.20″.60 morning magnetic amplitude, and 50′.30 evening amplitude, without diurnal period (*sin periodo diurno*), exceeding the ordinary deviation by 2′.2″. The night was very clear and fine. At 1.40 a.m. a subterraneous rumbling was heard, followed by a strong undulatory movement, which, running from S.W. to N.E. culminated in Imbabura, expending it force upon the hills, plains and towns; precisely in the direction of the magnetic declination curve passing through Quito, as laid down in map 10 of the great atlas of Garnier.

The earthquake felt in Bogotá on the night of June 4th, 1870, was also undulatory, and was propagated from S.W. to N.E- in a direction exactly contrary to that of the magnetic de. clination curve passing through Bogotá, and was preceded by magnetic disturbances analogous to those observed in Quito. The following is an account of the earthquake of June 4th 1870, at Bogotá by Señor José Maria Gonzales, the editor of the *Scientific Review* in this City.

On June 4th, between 3 and 4 p.m., deafening subterraneous noises were heard very prolonged and something like the sound of a distant waterfall. This, combined with continual agitations and considerable deviations of a very sensitive magnetic needle which was constantly observed, gave warning of the approach of an earthquake. And in fact, at 9.20 p.m. a deviation of the needle of 0°15′ towards the East was observed, and at 9.40 p.m. a strong horizontal rectilinear shock was felt, the seismic wave moving from S.W. to N.E. The concentrated seismic wave was felt during 3 seconds, and the retarded wave kept up an undulatory movement (only perceptible by the instruments) during 14 minutes 35 seconds. During the passage of the concentrated wave, the magnetic needle attained a maximum deviation of 0°45′ to the East, exhibiting at the same time a sharp trembling, which slowly decreased and terminated in 13 minutes 55 seconds.

The proper correction being made in the pendulum for the velocity attained, it appears that the shock lasted 14 minutes 3 seconds. From that time perfect calm continued until 2.10 a.m. when the magnetic needle showed a slight undulatory movement. At the same time a pendulum of 2 inches acquired a slight rotatory movement in the form of an ellipse of great eccentricity, with the major axis in the direction North 35°30' East. During this second shock, which lasted 10 minutes 15 seconds, the waves followed each other at intervals of 30 seconds approximately, and lasted from 2 to 3 seconds each.

On June 5th, at 10.35 p.m., a very slight undulatory movement was observed, only perceptible by the indications of a very sensitive instrument. It lasted 10 minutes 15 seconds. It was not continuous like that which occurred at 2 a.m. on June 4th, and caused no considerable deviations of the magnetic needle.

The greater number of earthquakes which have occurred in this part of America have taken place at the time of the Equinoxes, that is, at the time when the thermo-magnetic currents are most powerful. This gives some reason for suspecting that they are the cause of those strong undulatory earthquakes which extend over a large surface of the country, since the direction of these had nearly always been the same as that of the magnetic curves. This only applies to those shocks which are *strong* and extend over a *large* area, for the slight local shocks, not undulatory in their nature and not extending to any great distance, are caused by movements of the earth or rocks in the interior of the mountains; a great part of the Andes containing calcareous strata, and being therefore cavernous (as M. Boussingault has observed) are liable to subside."

Many instances where magnetic storms and earthquakes have occurred at or about the same time have been collected by Kreil (*Der Naturforscher* No. 27, p. 242).

On April 18th, 1842, at 10h. 9m. a.m., Lamont observed a sudden change, in a declinometer in Munich. At the same time Colla observed a similar disturbance in Parma and during the same minute there was a severe earthquake in Greece. (Lamont, "Astronomie und Erdmagnetismus," p. 277.). A similar observation is noted in Poggendorff's Annalen Bd. CXV., p. 176. This occurred on December, 26th, 1801, at 8h. a.m. when instruments for declination, inclination, and for intensity showed unusual movements simultaneous with which there had been severe earthquakes in Greece.

At the Magnetical Observatory in Tokio, where magnetic elements have been automatically recorded for the past few years, there does not appear to have been disturbances at about the time of earthquakes more than those which might be accounted for as being due to mechanical movement. Such irregularities are most noticeable in the lines indicating variation in declination. They are occasionally noticed in the records for horizontal force, but hardly ever in the curves for dip, these latter parts of the instrument taking up less movement than that which records declination.

In *Nature* of March 3rd, 1887, Mr. G. M. Whipple, superintendent of the Kew Observatory, gives a copy of the diagram obtained from the bifilar magnetograph at his observatory, showing the movement produced by the Riviera earthquake of February 26th. The magnetograph disturbance occurred at 5.40 a.m. Similar disturbances were observed at Perpignan, Paris, and Lyons, and M. Mascart observes that these disturbances were simultaneous, and it was not therefore an oscillatory movement passing from point to point which had to be considered, but a phenomenon affecting a large area simultaneously.

The most carefully studied magnetical and electrical phenomena which have accompanied volcanic and seismic disturbances are those which occurred at the time of the eruption of Krakatoa on August 27th, 1883.

The magnetical disturbance on this occasion passed from the east towards Europe being recorded later and later as it progressed westward. Ordinary magnetic movements are almost simultaneously produced at different parts of the earth's surface. The stations at which observations were made were Zi-ka-wei, Colaba, Mauritius, Pawlowsk, Vienna, Kew, Stonyhurst, and Lisbon.

The average values of travel were :—

For declination	....	761 miles per hour.
For horizontal force	....	939 miles per hour.
For vertical force	....	927 miles per hour.
Final true mean	....	868 miles per hour.

At Batavia the magnetical disturbance was attributed to the magnetic iron contained in the rain of ashes. (Report of the Krakatoa Committee of the Royal Society 1888.)

Whether we are to consider that there has been a relationship between seismic action and terrestical magnetism definitely established is yet an open question. The observations so far as they have gone have, however, been sufficient to justify further research upon this subject. Rossi holds the opinion that the phenomena which have been observed are not purely mechanical, and that at the time of an earthquake there is an electrical action which more or less paralyzes a natural magnet. [*Metrologia Endogena*, Vol. I. p. 83, &c.].

If we admit that the earthquakes of certain regions are the outcome of volcanic energy, and at the same time bear in mind the intensely magnetic character of many lavas, the possiblity of a connection between local variations in terrestrial magnetism and seismic phenomena is apparent.

The lavas of the Hawaiian Islands affect the needle of an ordinary theodolite. In Iceland and in Japan I have picked up pieces of lava which will cause the needle of an ordinary compass to revolve. The surface soil of the latter country is saturated with grains of magnetite derived from the decompositions of volcanic rocks.

Some of the volcanoes in Japan, like Mont Nuova in Italy, came into existence during the historical period, and with their origin which was accompanied with seismic phenomena it seems impossible that there should not have been enormous local changes in magnetic elements.

Not only have the effects visible to us on the surface of the earth to be considered when discussing this question, but the effects which take place beneath the surface, such as the formation of dykes and general alterations in the arrangement of the magnetic magma from which these dykes originate.

Effects of cooling also might possibly produce slow changes in the magnetic intensity of a volcanic region. Dr. E. Naumann tells us that as you approach Ganjusan, a volcano in northern Japan, there is evidence of a change in declination which near the mountain amounts to 14°, and that this change has taken place during the last 80 years. [Trans. Seis. Soc. of Japan, Vol. VI.].

If earthquakes are indicative of a change in the character or the position of a magnetic magma beneath the earth's crust, to seek for evidence showing that seismic phenomena are connected with magnetic variations is not unreasonable.

Since writing the first part of this paper, Mr. P. Mayet has called my attention to the following curious phenomena observed upon the Sonnblick, a mountain in the Austrian Alps 10,154 ft. high (see *Die Gartenlaube*, No. 21,890, p. 35).

At the meteorological station on this mountain Dr. Wilhelm Trabert observes that a storm is not heralded by dark clouds, thunder, and sultry weather. The warning of the coming storm is however given by a crackling in the telephone. This is some times quite loud. The passage of sparks between the plates of the lightning arrester and the ringing of the bell indicate that the telephone must be thrown out of circuit. When the storm comes sleet and hail strike the window and a lightning rod may be struck, and *when the lightening strikes the house it shakes as if in an earthquake.*

ATMOSPHERIC ELECTRICITY AND EARTHQUAKES OF TOKIO.

At the Imperial Meteorological Observatory in Tokio, atmospheric electricity during the greater portion of the last two years has been automatically recorded by the photographic arrangement of Mascart.

In this system the needle of an electrometer which has a bifilar suspension is kept at the potential of the atmosphere by connection with a water dropper, while the quadrants of the electrometer are kept at a constant potential by connection with 50 water Daniels.

Through the kindness of the Director of the Observatory, Mr. Arai Ikunosuke, a few days ago a series of records extending over a period of twelve months were placed at my disposal for examination, I have compared these not only with the records of earthquakes obtained in Tokio but with the records of earthquakes which have been noted in various parts of Japan.

A glance at these records at once showed that at the time of certain earthquakes there was a change in potential, the air suddenly becoming electro-negative,—the mirror turning so quickly to a new position that its movement could not be photographically recorded. From the new position, however, after several hours it gradually fell back towards the line from which it had deviated. The accompanying diagrams are illustrations of these changes. The horizontal line in each of these figures is a datum for reference. When the diagram is above this the air is negative relatively to the earth, and when below it, it is positive. The numbers along these lines are the hours of the day and night, p.m. being to the left of the central line and a.m. to the right.

If you discharge the electrometer by placing your finger on one of the connections leading to the water dropper the spot of light swings to zero. On removing your finger it quickly returns to its original position. Shaking the pipe with an insulated glass rod Mr. Outsuka, who is in charge of this department, informs me produces no effect upon the reading.

From Fig. 1 we see that between 4 and 5 p.m. on April 3rd the air at the time of an earthquake suddenly became electro-negative, and the potential was not restored until 5 a.m. on April 4th.

A somewhat similar change is shown in Fig. 2 and in Fig. 3, but in Fig. 3 at about 8 p.m. there is a sudden change in an opposite direction without an earthquake.

In Fig. 4, between 2 and 3 p.m. on April 18th, the mirror was moving to and fro so quickly or else was so far displaced that no record was obtained. An earthquake happened at 2.7 p.m. which was very large, at 2.54 p.m. which was small, and again at 3.39 p.m. which was also large, but there is no reason to suppose that the ground was in constant motion during the time that the spot of light from the mirror failed to record.

The displacement at about 6 a.m. on April 19th as well as those shown in Figs. 5 and 6 were not accompanied by earthquakes, although several earthquakes occurred upon the same days.

Fig. 7 shows an irregular diagram of ordinary occurrence.

From these few diagrams it would appear that certain earthquakes are accompanied by sudden changes in the diagrams, that other earthquakes occur within a few hours of such changes and that similar changes may occur without earthquakes.

Records of Earthquakes and Electrical Disturbances.

1888.

October 9th, 1.07 a.m.—Slight shock in Tokio and at one place 30m. E.

No electrical disturbance.

October 10th, 4.20.24 p.m.—Tokio only.

Cannot read electrometer diagram.

October 12th, 9.40.56 a.m.—Tokio and a few places to North.
Difficult to read, but apparently no electrical disturbance.

October 20th, 6.20.6 a.m.—Tokio and 120 miles to N.-East.
No electrical disturbance.

Nearly all the Electrometer diagrams for this month are difficult to read, but from what can be seen there was little disturbance in Tokio. During this month there was no severe earthquake with its origin near Tokio.

November 2nd, 1.45 p.m.—A large area shaken extending to North East and West. The origin 30 or 40 miles North of Tokyo.
Electrical disturbance zero.

November 3rd, 0.51.0 a.m.—Small area near Tokio.
No electrical disturbance.

November 3rd, 8.15.0 a.m.—A large area to N.E.
No disburbance.

November 5th, 14.22 a.m.—Tokio and to East.
No electrical disturbance.

November 6th, 4.38 p.m.—Tokio only..
No electrical disturbance.

November 9th, 10.22.34 p.m.—Tokio only.
A blurred displacement as if by a swing of the mirror.

November 10th, 1,37.44 p.m.—Tokio only.
No displacement.

November 16th, 0.42.49 a.m.—Tokio only.
A blurr indicating a swing of the mirror.

November 20th, 0.50.0 a.m.—Tokio and 100 miles N.E.
No electrical disturbance.

November 22nd, 1.27.43 p.m.—Tokio only.
No electrical disturbance.

November 23rd, 5.23.30 p.m.—Tokio only.
No disturbance.

November 24th, 2.00 a.m.—Extending from Sapporo to the South of Tokio.
No electrical disturbance.

November 25th, 4.50.15 p.m.—Tokio only.

Electrical disturbance 6 mm. downwards or positive. This may be due to filling the water dropper.

During November with the exception of a sudden change at 1 a.m. on 26th November (when there was no earthquake) the air becoming negative, there is no sudden change such as night accompany earthquakes.

December 3rd, 0.24.47 p.m.—Tokio and to S.E.

Disturbance zero.

December 6th, 6.27 a.m.—Very large disturbance from Nambu to Tokio.

No electrical disturbance or zero.

December 16th, 4.19.03 a.m.—Tokio only.

No records taken.

December 28th, 3.28.04 a.m.—Tokio only.

No disturbance.

No marked sudden electrical disturbance occurred during December and although there were many earthquakes in Japan but few were felt in Tokio.

1889.

January 1st, 3 p.m.—Tokio near the centre of a feeble earthquake.

No electrical disturbance.

January 1st, 7.5.30 p.m.—Tokio the centre of a severe earthquake. extending 100 miles N. and to the S.W.

By the electrical disturbance the record left the paper.

January 3rd, 7.58.6 a.m.—N.E. and S.W. from Tokio.

By electrical disturbance the air became 50 mm. negative. Fell back in 6 hours.

January 12th. 18.34.3 p.m.—Slight and to N.E.

Disturbance zero.

January 27th, 2.28.47 p.m.—Very slight—Tokio only.

Disturbance zero.

During this month at about 4 p.m. and 7 a.m. there was often a large disturbance which takes some hours to work back. Was or was not this produced by filling the water tank? Condensation of moisture on the outside of this might weaken the insulation until the moisture was dissipated.

February 5th, 12.27.39 p.m.—S.N. slight—Tokio only.

Disturbance nothing more than an extreme irregularity which was going on before and after the earthquake.

February 6th, 3.20.5 p.m.—E.W. slight—Tokio only.

Disturbance zero.

February 9th, 9.41.38 a.m.—S.N. very slight—Tokio and to N.W.

Disturbance zero.

February 15th, 5.14.3 p.m.—Very slight—Tokio only.

Disturbance zero.

February 18th, 6.9.39 a.m.—Duration 6m. 12s. S.W. Horizontal Period 2.2. Horizontal Amp. 20.33. Vertical Period .6. Vertical Amp. 3·7.

Felt in Tokio and many miles north and west. Origin near Tokio. Severe.

6.27.45 a.m.—Duration 2m. 0s. S.W.-N.E.—Am. 0.2.

Tolerably large area round Tokio, but feeble.

7.48.52 a.m.—Duration 2m. E.-W. slight.

Tolerably large area round Tokio, but only felt at a few places.

By the electrical disturbance air became 15 mm. negative and remained so from about 6.15 to 7.30 a.m., when it suddenly returned.

8.2.0 a.m.—Slight. Tokyo only.

10.10.56 a.m.—0m. 30s. S.E.-N.W., slight, but a considerable area shaken.

For both the above a slight movement may be traced on the electrometer diagram.

February 19th, 2.57.43 p.m.—Duration 0m. 15s. S.W., slight. Tokio only.

Disturbance zero.

February 20th, 9.19.37 p.m.—Very slight. Tokio only.

Disturbance zero.

February 21st, 5.52.21 a.m.—Duration 0m. 15s. E.-W., slight, but felt as far as Odawara to west.

Disturbance zero.

February 8th, 19.23 a.m.—Duration 0.20 S.-N., slight. Tokio only.

Disturbance zero.

February 11th, 1.4 a.m.—Duration 0.30 slight. Tokio and to west.

Disturbance zero.

February 9th, 27.52 p.m.—Duration 15 S.-N., slight. Tokio only.

Disturbance zero.

February 23rd, 11.27.21 p.m.—Duration 0m. 13s. S.-N., slight. Tokio only.

Disturbance zero.

March 3rd, 4.35.19 p.m.—Duration 0m. 30s. E.-W. Amp. .2 mm. Tokio only.

Very slight, 1mm. negative.

March 4th, 7.24.25 a.m.—Slight. Tokio only.

Electrical disturbance, 2mm. positive.

March 18th, 6.41.12 a.m.—S.-N. Tokio only.

Electrical disturbance, only a swing of mirror.

March 21st, 6.09.23 p.m.—Slight. Tokio and Yokosuka.

Disburbance zero.

March 26th, 2.41.48 p.m.—Tokio only.

Slight irregularity.

March 28th, 1.20.10 a.m.—Horizontal period 0.6. Amp. 4.1. Vertical period 0.5. Amp. 0.6. E.S.E.-W.N.W. 1 min. 30 sec.

March 28th, 10.22.55 a.m.—Period 0.5. Amp. 0.5. Vertical Period 0.4. Amp. 0.1. S.E.-N.W. 1 min. 15 sec.

March 28th, 7.18.23 p.m.—Horizontal period 0.2. Amp. 0.2. E.-W.

The first was strong with Tokio near the centre. Electrical displacement 6mm. negative which remained for 4 hours.

The other two, which were relatively feeble, with the centre to the N.W., do not shew any disturbance.

March 31st, 6.42.15 a.m.—Period 2.5. Amp. 3.8. Vertical Period 0.6. Amp. 0.2. S.S.E.-N.N.W. 4. min.

March 31st, 8.13.03 a.m.

March 31st, 5.59.42 p.m. Period 0.7. Amp. 1.2. S.W.-N.E. 2.0 min.

The first shock extended N.E. to Sendai. There was a sudden negative disturbance of 10 mm.; after a ¼ of an hour there was a strong change to positive but this latter was gradual.

April 3rd, 4.27.21 p.m.—Horizontal. Period .7. Amp. 1.5. Vertical. Period .3. Amp. .2. S.E.-N.W. 1 min. 30 sec.

Area of shock about 80 by 80 m. with Tokio near centre.

Electrical Deviation was 22 mm. negative and a gradual return in 9h.

April 3rd, 4.40.51 p.m.—Area 60 m. E.-W. and 30 m. S. Origin to S. of Tokio. Deviation nothing.

April 6th, 7.40.13 a.m.—Period .5. Amp. .3. S.W.-N.E. 0 min. 50 sec.

Area about 70 by 70 m. with Tokio in southern part of ellipse.

Electrical deviation 15 mm. negative. Returns in 6h.

April 8th, 0.48.00 p.m.—Area about 170 by 70 m. with Tokio in southern extremity of circle of disturbance. Deviation 10 mm.

April 8th, 8 p.m. Negative distubance of 12 mm.

April 14th, 5.22.54 a.m.—An ellipse with principal axis running 60 m. N.E. with Tokio at southern extremity. Feeble. Only felt at three places. Deviation zero.

April 17th, 9.41.43 p.m.—Large area 150 m. N.E. from Tokio. Not felt south of Yokohama. Deviation zero.

April 18th, 9.45.0 p.m. to 10.15.0 p.m.—The swing of the mirror left a gap.

April 18th, 2.07.42 p.m,—Period 1.0. Amp. .8. Vertical Period .7. Amp. 2. E.S.E.-W.N.W. The area shaken was about 18,000 square miles with Oshima as centre and 100 miles radius. Severe and long.

April 18th, 2.54.11 p.m.—Tokio only.

April 18th, 3.39.08 p.m.—Period .9. Amp. .3. S.E.-N.W. with Oshima as centre, 60 m. radius.

April 18th, 4.00.01 p.m.—Tokio only. Deviation and a gap from 2 to 3 mm. long formed by swing of the mirror.

April 19th, 0.18.46 a.m.—Area 60 by 30 m. Tokio at S.W. end of ellipse. Deviation 2 mm. positive.

April 19th, 2.29.19 a.m.—Deviation zero. Felt only at Tokio.

April 19th, 6.00.00 a.m.—20 mm. positive.

April 19th, 3.00.27 p.m.—Period .6. Amp. .2. S.W.-N.E. 50 sec. Area 60 by 30m. Tokio at S.W. end of ellipse. Deviation 1 mm.

April 19th, 5.50.39 p.m.—Period .6. Amp. .2. E.W. 1m. 30sec. Feeble, not extending beyond 120 m. N.E. Deviation 1 m. positive.

April 19th, 5.00.00 p.m.—Deviation 20 mm. negative.

April 19th, 10.53.55 p.m.—Felt at Tokio only. Deviation zero.

April 20th, 1.00 a.m.—Deviation 8 mm.

April 20th, 10.45 a.m.—Deviation 6 mm.

April 20th, 4.50.33 p.m.—Felt in Tokio only.

April 20th, 7.00 p.m.—Deviation 40 mm.

April 21st, 0.30 a.m.—Deviation 20 mm.

April 22nd, 0.30 a.m.—Deviation 10 mm. A small earthquake 60m. N. of Tokio.

April 27th, 1.30 to 2 p.m.—E.W. 30 sec. A large area extending 150m. N. from Tokio and 80 m. in breath. The swing of the mirror left a gap.

April 28th, 3.07.43 a.m.—Deviation 60 mm.

April 29th, 1.56.28 a.m.—Deviation 6 mm. A small earthquake 60 m. N. of Tokio and also felt in Tokio. E.W. 20 sec.

May 6th, 11.41.41 p.m.—Period .5. Amp. .4. S.S.W.-N.N.E. 1 mm. Deviation zero. Tokio on S.-W. edge of a shaken region (60×60m.) Disturbance feeble.

May 7th, 10 p.m.—Deviation 40 mm.

May 8th, 5.05.34 a.m.—Deviation 15 mm. S.N. 30 sec. Tokio on west side of long narrow ellipse extending 60 m. N. and 30m. S.

May 8th, 0.24.07 p.m.—Only felt in Tokio. Duration indistinct.

May 9th, 1.00 p.m.—No earthquake, but a deviation 70 mm.

May 12th, 10.42.11 a.m.—Period 2. Amp. .6. S.S.E.-N.N.W.

Very large earthquake with centre near Nagoya, and reaching from south of Kobe to north of Tokio. Dev. zero.

May 17th, 6.39.15 a.m.—Felt only in Tokio. Dev. zero.

May 17th, 8.34.25 a.m.—Felt only in Tokio. Dev.+3mm.

May 17th, 9.20.35 a.m.—Felt only in Tokio. Dev.+2mm.

May 17th, 9.39.37 a.m.—Felt only in Tokio. Dev. zero.

May 17th, 10.30 a.m.—Dev.+3mm.

May 17th, 1.46.32 p.m.—Felt only in Tokio.

Three deviations, between 1 and 5 p.m. back and forth.

May 20th, 0.23.30 p.m.—Disturbance extended from Tokio 120 miles N.E.

Deviation indistinct.

May 20th, 6.45 p.m.—Dev.+4mm.

May 25th, midnight to 1 a.m. 26th.—3 large disturbances.

May 27th, 6.22.56 p.m.—Felt in Tokio only. E.-W. 12 sec. Dev. zero.

May 28th, 5.26.22 a.m.—Felt in Tokio only. E.-W. 15 sec. Dev.—10mm.

May 30th, 10.27.22 p.m.—Period .8. Amp. .4. S.E.-N.W. A large disturbance extending from Hakone 120 miles N.E. and 80 miles in breadth.

Deviation-diagram indistinct.

June 1st, 6.15.21 p.m.—Period .5. Amp. .2. E.-W. 25 sec. Dev.—1mm.

Disturbance extended from Tokio 80 miles N.E. and 80 miles in breadth.

June 3rd, 1.51.30 p.m.—Extended from Tokio 120 miles N.E. Dev. zero.

June 5th, 8 p.m.—Dev.+20 mm.

Several days great electrical disturbances, but no earthquakes.

June 14th, 0.26.41 p.m.—From Tokio the disturbed area extended about 60 miles N.E.

Deviation indistinct.

June 15th, 10.10.02 a.m.—Felt in Tokio only 50 sec. Deviation indistinct.

June 16th, 2.31.24 p.m.—Felt in Tokio only. S.E.-N.W. 30 sec. Deviation at 2.45 p.m.—8 mm. Deviation at 8.30 —40 mm.

June 20th, 9.51.10 p.m.—Period .6. Amp. 5. S.E.-N.W. 1 min. 30 sec. From Yokohama the disturbed area extended 150 miles north and was 70 miles broad. The centre was to the N.E. Deviation zero.

June 26th, 1 p.m.—(About). Deviation 10 mm.

June 27th, 7.09.17 a.m.—Period .0. Amp. .5. E.-W. 1 min. Shaken area from an origin near Owari and extending N.E. to Tokio. Deviation 6 a.m.—7 mm. Deviation 7 a.m.—1 mm. Deviation 7.30 a.m.—5 mm.

June 29th, 10.45.—Deviation 15 mm.

July 3rd, 5.39.58 p.m.—Period .5. Amp. .3. E.-W. 40 sec. Deviation zero. Disturbed area extended 60 miles N. from Tokio, where it was 60 miles broad.

July 5th, 6.22.31 p.m.—Felt in Tokio only. Deviation+1 mm.

July 5th, 8.57 p.m.—Felt in Tokio only. Deviation—2 mm.

July 6th, 8.30 p.m.—Deviation+40 mm.

July 10th, 8 p.m.—Deviation—20 mm.

July 10th, 11 p.m.—Deviation+15 mm.

July 12th, 9.45 a.m—Deviation—8 mm.

July 15th, 8.45 a.m.—Deviation+5 mm.

July 17th, 9 a.m.—Deviation+20 mm.

July 18th, 10.33.18 p.m.—S.-N. 35 sec. Deviation zero. Extends from Tokio 60 miles N.-E.

July 30th, 2.03.40 a.m.—E.W. 10s. Area shaken extends from Tokio 40 miles N. and E. Deviation + 10mm. The swinging of the mirror showed a gap of 5m. The mirror swung negative and positive through 10mm.

July 30th, 2.15 p.m.—Deviation + 5mm.

August 2nd, 10.21.06 a.m.—Horizontal period .5. Amplitude 1.3. Vertical period .3. Amplitude .4. N.E.-S.W. 1m. 30s. Deviation zero. Extended from Odawara 150 miles N.E. past Tokio. Area 100 miles broad.

August 2nd, 2.36.12 p.m.—Extended from Tokio 180 miles north to Sendai. Deviation zero.

August 5th, 7.34.56 a.m.—Period 1.7. Amplitude 1.7.—E.S.E.-W.N.W. 4m. 20s.; shaken area from Odawara 180 miles to N.E. Deviation zero.

August 15th, 0.06.21 p.m.—Felt Tokio only. Deviation zero.

August 20th, 5.20.23 p.m.—Period .8. Amplitude .3. S.-N. 50s. from Tokio 60 miles to north and 30 miles to south. Deviation 20m. or more negative.

August 21st, 1.07.44 p.m.—Tokio only. Deviation indistinct.

August 26th, 3.27.13 p.m.—Horizontal period .6. Amplitude 1.4. Vertical period .4. Amplitude .2. E.-W. 1m.; Shaken area extends 50 miles north of Tokio and 20 miles south. Was strong near Yokosuka. Deviation zero.

August 30th, 3.06.22 p.m.—Period .1. Amplitude .4. E.S.E.-W.N.W. 3m. 30s. Felt in Tokio only. Deviation zero.

September 15th, 2.34.06 a.m.—Felt in Tokio only. Deviation zero.

September 16th, 6.37.30 a.m.—Period .7. Amplitude 1.3; W.S.W.-E.N.E. 1m. 30s. Felt 60m. north of Tokio and 20 miles south. Strong near Yokosuka; area 80 miles broad. Deviation zero.

September 17th, 2.04.28 a.m.—Felt in Tokio only. Deviation zero.

September 20th, 10.27.01 a.m.—Felt in Tokio and 60 miles to the east and 20 miles to the north. Deviation zero.

September 22nd, 1.56.33 a.m.—Felt in Tokio only. Deviation 8mm.

September 30th, 7.41.27 a.m.—Felt in Tokio only; 60 miles to N.E. Deviation zero.

Conclusions respecting the Tokio Observations.

Until farther investigations have been made, the following conclusions must only be regarded as tentative. They are as follows:—

1.—If there is a strong disturbance shaking an area 60 or more miles in diameter with Tokio near the centre, the air suddenly becomes strongly negative. This has occurred 10 times. To this rule there has been only one exception. There are two cases where the centre of the disturbances appears to have been 25 miles south of Tokio. These earthquakes have not always been accompanied by vertical motion and they have occurred at different hours.

2.—If there is a feeble disturbance only felt in Tokio, such disturbances have been 13 times accompanied with feeble electrical disturbances and 31 times without.

3.—When Tokio has been at the S.W. corner of an ellipse of disturbance, the centre of which may have been 15 or 20 miles to the N.E. there have been 3 cases when we have had electrical disturbances and 12 cases without such disturbances.

4.—When the centre has been 50 or 60 miles north-west of Tokio, there have been 2 cases of electrical disturbance and 11 cases without such disturbance.

5.—When the earthquake has shaken a narrow band extending from Tokio 30 miles north, there have been 3 cases of electrical disturbance and no instance of no disturbance.

6.—When the centre of a disturbance has been 20 or 30 miles east of Tokio there has been one case of electrical disturbance and six cases with no disturbance.

7.—When the centre of disturbance has been from 20 to 100 miles west of Tokio there have been 3 instances of electrical disturbance and 3 instances where there was no disturbance.

8.—At the time of earthquakes in Japan which did not reach Tokio there have been no sudden disturbances.

9.—In electrical disturbances which accompany earthquakes the air almost invariably becomes electro-negative, the potential suddenly rising sometimes as much as 30 volts. From this it is usually several hours before it returns to its normal condition.

DISCUSSION.

Dr. Knott called attention to the different character of the various coincidences which had been mentioned by Professor Milne. There was not the least doubt that the Krakatoa eruption had produced magnetic disturbances; and Professor Schuster's recent discussion of the diurnal variation in the magnetic force at any point on the earth's surface enabled us pretty well to explain the effect. It is well-known that every day the magnetic needle moves first to this side and then to that of its mean position. In Tokyo the amplitude of this diurnal oscillation is sometimes as much as 11 minutes of angle. Now Schuster has shown, by an elegant discussion of Gauss's theory of terrestrial magnetism, that this diurnal change is due to causes above us—electrical currents, say, brought into existence by the sun's action on a heterogeneous atmosphere. In the Krakatoa eruption immense clouds of dust were driven off into the higher atmosphere, and soon drifted round the whole globe, causing the remarkable sunset glows of the autumn of 1883. This dust, shot forth with immense velocity, would almost of necessity be electrified; so that we have the conditions for the existence of a highly electrified cloud of particles drifting along in the upper regions of the atmosphere. Such an electrical movement would have the characteristics of an ordinary electrical current, which might well affect the delicate magnetographs in India and Europe. But such an explanation cannot be applied to earthquakes. Professor Milne, in his historical sketch, mentioned a hypothesis brought forward by an Italian, which seems capable of development into a plausible enough explanation of a relation between earthquakes and atmosphere electricity. It must be remembered that when we say the air becomes more negative, we might as truly say the earth becomes more positive. It is the *difference* of electrical conditions between the earth and air that is measured. Now any sudden change of state from liquid to aqueous we know to be accompanied by electrical change. Hence an explosion in some earth cavity might easily change the electrical condition of the earth in the vicinity. This electrical change on reaching the surface—it might be a little ahead of the shock—would affect the electrometer. It was, however, too soon, perhaps, to suggest explanations before the facts had been thoroughly established. But in any case the Society and science generally are benefited distinctly by Professor Milne's peculiar faculty of ever opening up new lines of research.

Mr. Mason remarked that he had many years ago tried to discover electrical disturbance in land and ocean telegraph lines, which might be related to earthquakes. But he had failed to make out any connection. The truth was, indeed, that Japan was comparatively free from telegraphic disturbances. In England, on the other hand, telegraphic lines were frequently disturbed, so that business operations were distinctly interfered with. This comparatively rarely happens in Japan.

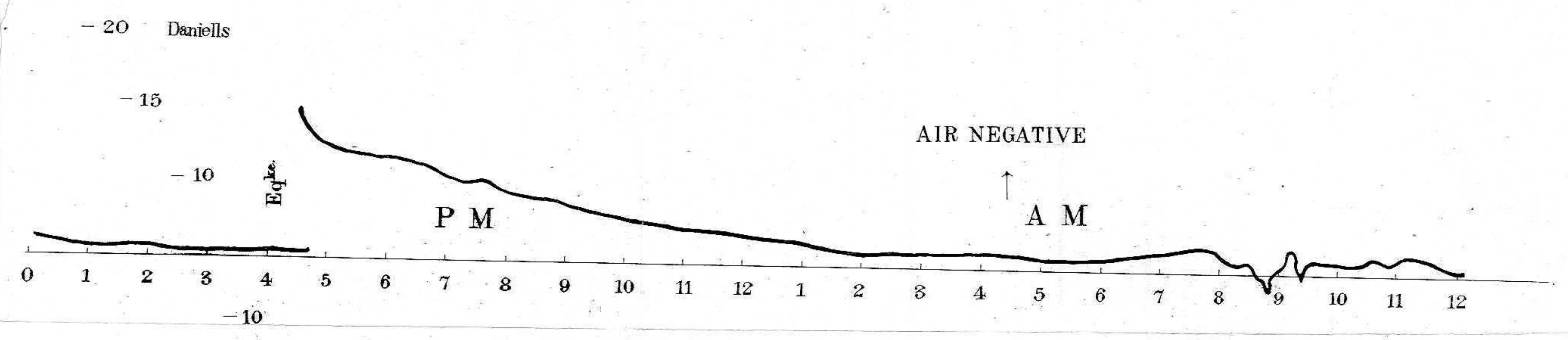


Fig 1. APRIL 3–4 1888

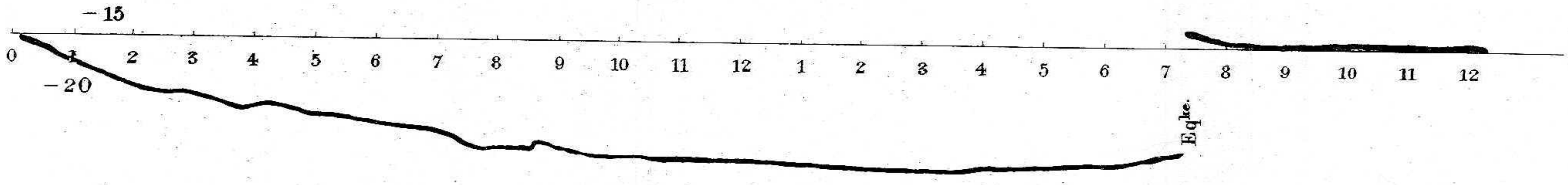


Fig 2. APRIL 4–5

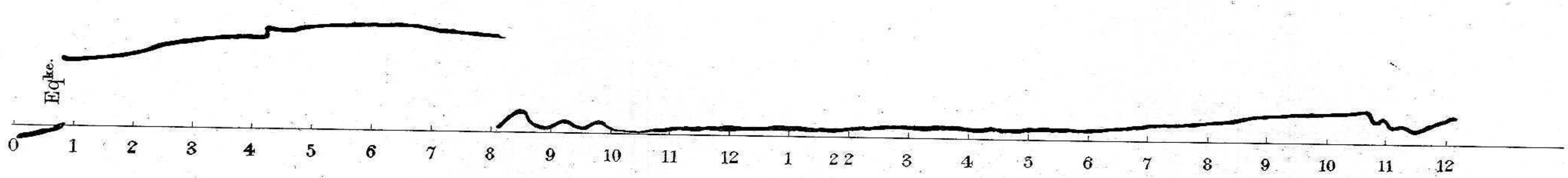


Fig 3. APRIL 8–9

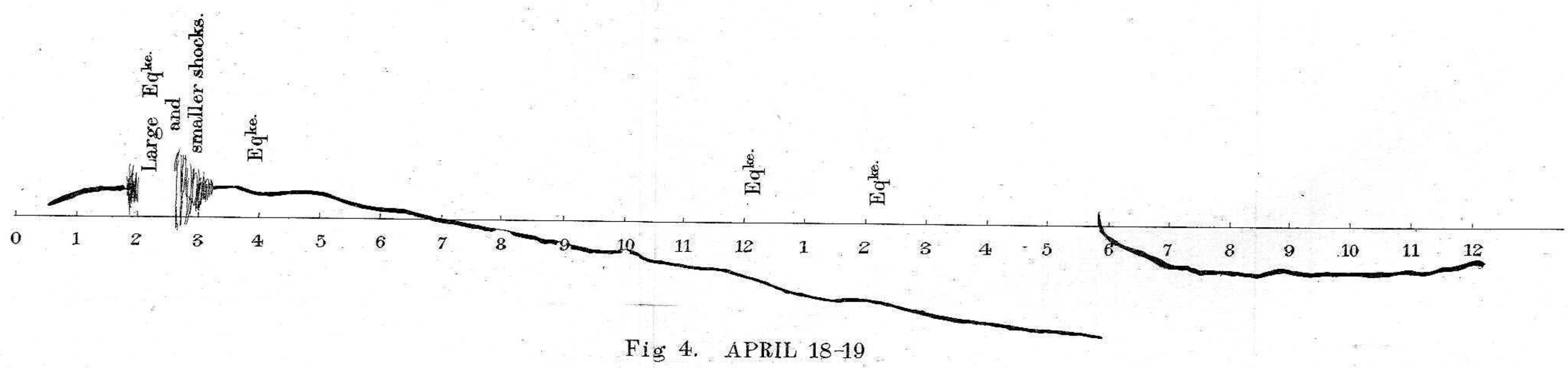


Fig 4. APRIL 18–19

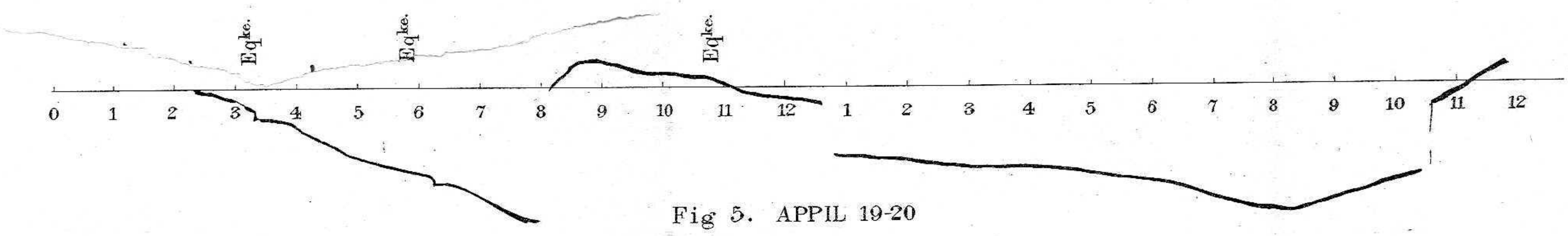


Fig 5. APPIL 19-20

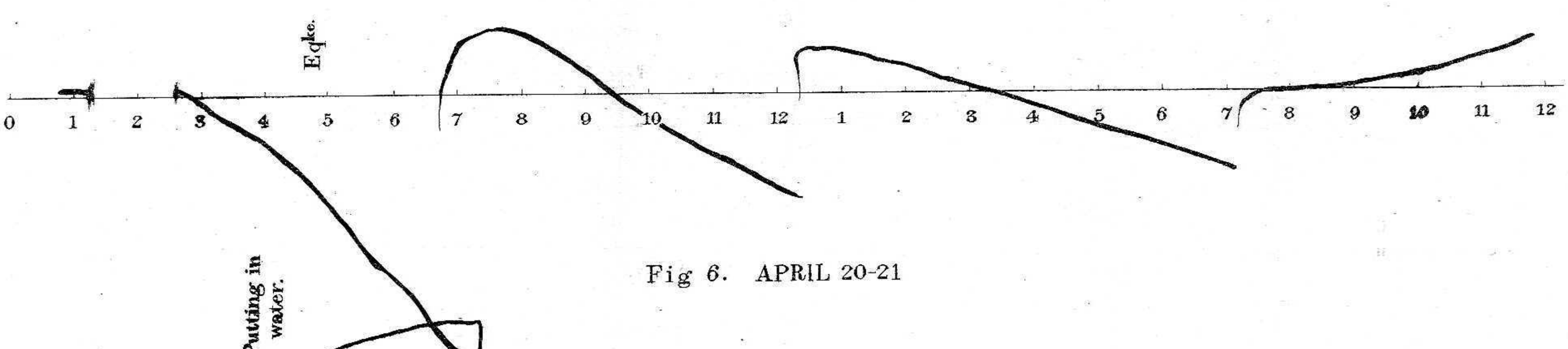


Fig 6. APRIL 20-21

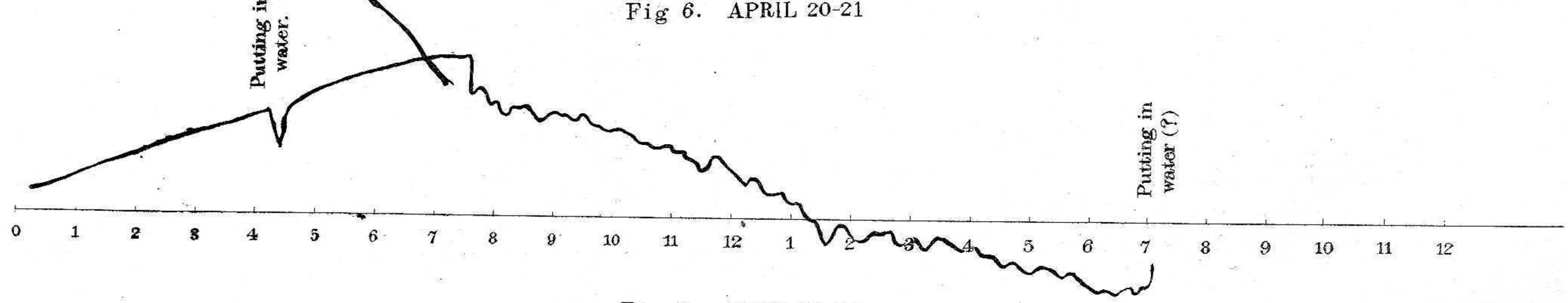
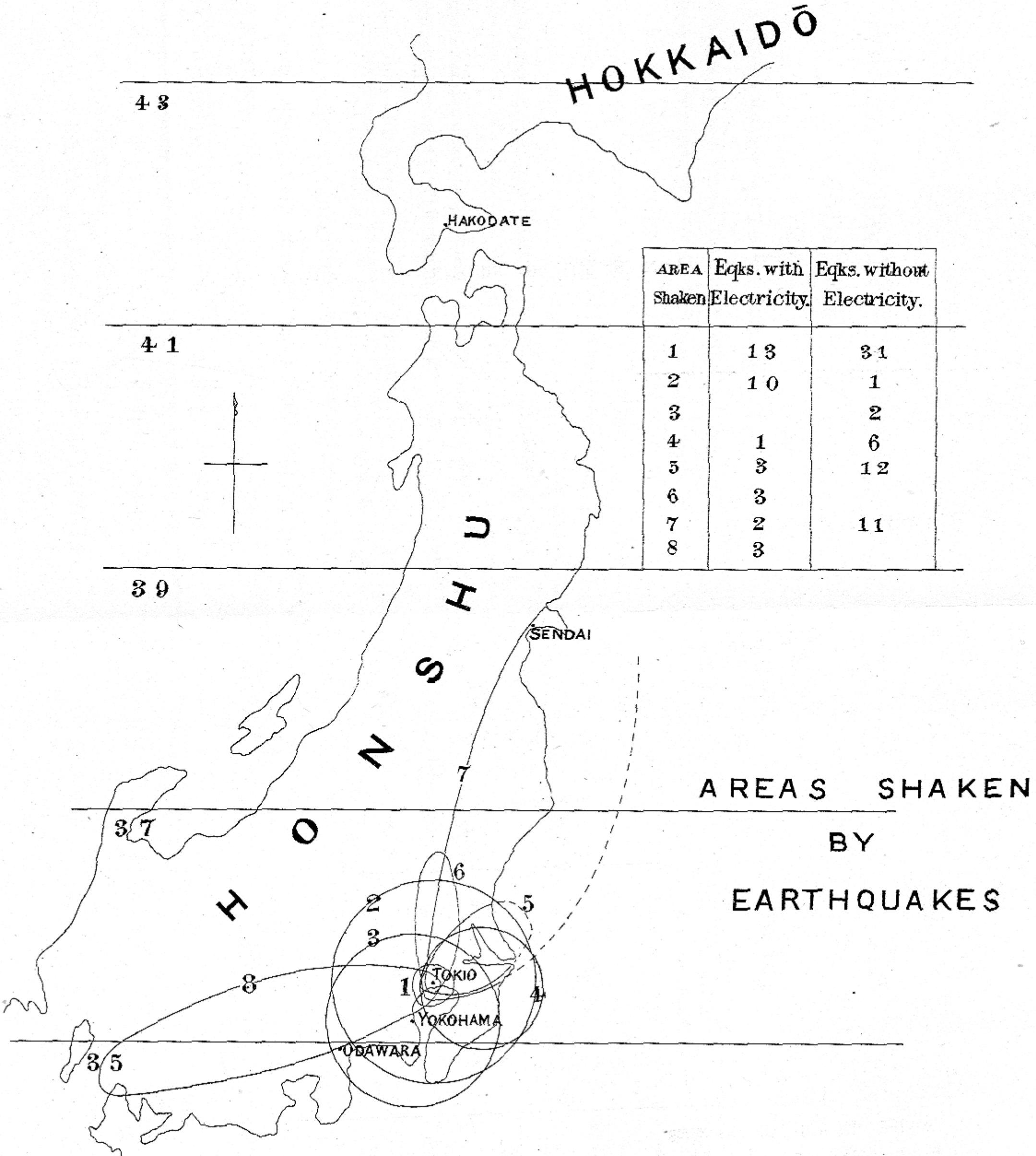


Fig 7. APRIL 24-25

RECORDS OF ATMOSPHERIC ELECTRICITY.



AREA Shaken	Eqks. with Electricity.	Eqks. without Electricity.
1	13	31
2	10	1
3		2
4	1	6
5	3	12
6	3	
7	2	11
8	3	

TOKIO IS NEAR THE CENTERS OF AREAS N°1 AND 2.