SEISMIC, MAGNETIC, AND ELECTRIC PHENOMENA.

By John Milne.

In Volume XV. of the Transactions of the Seismological Society of Japan the present writer published a paper on "Earthquakes in connection with electric and seismic phenomena." The subject was again referred to in the Tenth and Eleventh Reports to the British Association (1890 and 1891) on the Earthquake and Volcanic Phenomena of Japan.

The object of the present note is to show that although considerable attention has been given to the subject under consideration, so far, the balance of evidence precludes the idea of any direct connection between earth-shaking and magnetic and electric phenomena, and at the same time to record a few experiments made in connection with this subject which may possibly indicate lines of research in new directions.

Earthquakes and Magnetic Disturbances.

Earthquakes have often been accompanied by magnetic disturbances, as for example:—

In 1755 with the Lisbon Earthquake, observed by Sarti.

In 1799 with the Cumana Earthquake, observed by Humbolt.

In 1822 with the Auvergne Earthquake, observed by Arago.

In 1846 with the Tuscan Earthquake, observed by Pilla.

In 1851 with the Melfi Earthquake, observed by Palmieri and Scacchi.

In 1842 with an Earthquake in Greece, observed by Lamont.

In 1861 with an Earthquake in Greece, observed by Lamont.

In 1844 with the Andalusia disturbances observed at Lisbon, Greenwich, and Wilhelmshaven. In 1887 with the Ligurian Earthquake, magnetic disturbances were observed in many European observatories. Without entering into the discussion as to whether these phenomena were really magnetic, or simply mechanical, M. Mourreaux, Chief of the Magnetic Observatory of Parc Saint Maur, near Paris, suspended on the same stand as the magnetograph a copper bar having the same form as the magnetic one. The bifilar suspension for the copper bar was identical with that used in the magnetograph and the movements of each were recorded photographically.

In 1889, on May 30th, an earthquake shook the northern part of France.

Between July 11th and 12th an earthquake, having its origin as Verny, in Central Asia, disturbed the bubble of an astronomical level at Berlin and magnetic apparatus at Paris, Lyons, Perpignan, Nantes and Kew.

Between October 25th and 26th there was a third disturbance. Each of these three earthquakes disturbed the Magnetograph at Parc Saint Maur but did not disturb the record from the copper bar. This experiment has been discussed by G. Agamemone, Atti della Reale Accademia dei Lincei (Royal Academy of the Lincei, Vol. VI., January 5th, 1890), who points out that because the moments of inertia of the copper bar and magnetic bars were different and that the movement of one is dependent on a magnetic moment whilst the other is not, a given motion of the ground might set one in motion and not the other. It is therefore possible that the movements of magnetographs at the time of earthquakes may be the result of mechanical disturbance, and that we are not yet in a position to assert that earthquakes and magnetic phenomena have any direct relationship.

Professors Ayrton and Perry, when in Japan, did not succeed in finding any change in magnetic intensity at times

when Earthquakes occurred, and it may be added that the occasional slight disturbances in the photographic traces at the Magnetic Observatory in Tokio, which are coincident with the occurrence of Earthquakes, find their easiest explanation in the assumption that they were produced by mechanical shaking.

2.—EARTHQUAKES AND ELECTRICAL DISTURBANCES.

In 1756, Dr. William Stukely, addressing the Royal Society, endeavoured to show that Earthquakes were due to electrical discharges between the earth and sky.

On more than one occasion my attention has been drawn to the fact that Earthquakes in California[1] have decreased since the opening of the railroads, a fact supported by statistics and parallel to a similar coincidence in Japan. The inference drawn by those who attribute the origin of earthquake phenomena to electricity, that is, if they have any ideas on the subject is, I presume, that the laying of metals across a country has equalized potentials.

In connection with this, I may mention that in conjunction with Prof. Y. Yamakawa, I had occasion to measure the current flowing from one of the metals of the Tokyo-Yokohama Railway to the neighbouring earth. "The Earth" was wet, but the lines, ballast, and sleepers were dry. The result showed about .000032 ampéres.

3.—SUGGESTED HYPOTHESES AS TO CONDITIONS WHICH MIGHT BE CONNECTED WITH THE OCCURRENCE OF EARTHQUAKES.

In the atmosphere, as the result of actions which may be less intense than changes which are taking place beneath our feet, critical electrical conditions are brought about which, when destroyed not only disturb cubic miles of air, but mechanically shake buildings. A question which arises, is whether such accumulations, the existence of which are favoured by the in-

[1] In San Francisco from 1850-1865 136 shocks were felt, whilst from 1866-1881 only 88 were recorded.

sulating power of the air, act inductively on the earth beneath with sufficient strength to favour yieldings in the strata. Inasmuch as the stress cannot exceed that resulting from a force which would pull the electrically charged clouds downwards, the answer to this is apparently negative, we must next look beneath the surface of our earth for the source of electric accumlation. Cell-like chemical action and the earth currents observed daily at telegraph stations may give quantity sufficient to produce electro-metallurgical changes in the earth, but the potential is too low to admit that they are connected with destructive discharges.

Pyro-electrical conditions, evaporation, crystallization, solidification, cleavage, disruption, and under suitable conditions, the violent escape of steam, might each result in the development of electricity at considerable pressure.

Remembering that small hydro-electrical machines are capable of producing large quantities of electricity and have yielded sparks five and six feet in length, let the following conditions be assumed :—From a volcanic focus A., high pressure steam is escaping through fissures in an insulating medium to an area B. At B quantities of electricity may be accumulated, which from time to time might result in violent discharge. To carry the hypothesis farther, let B be separated by an insulating rock from a conductor C, in connection with the water, say of the ocean. B and C, with the non-conductor between, form a condenser and their charges are intensified. Here again critical conditions might from time to time be reached.

Without admitting that the last suggested conditions have an existence, I will now enumerate a number of phenomena which have been recorded, which should be influenced if earthquakes are in any way the result or the cause of electric display.

4.—EARTHQUAKES AND EARTH CURRENTS.

Electricians have repeatedly affirmed that Earthquakes and Earth Currents have a close relationship, and I have already

given many illustrations where such appears to have been the case. For example :—

1875, March 17th—An Italian earthquake accompanied by strong earth currents.

1871, March 17th—An earthquake preceded and succeeded by strong currents in the Anglo-American cables.

1881—Ischian earthquake signalled in cables.

1875, September—In Martinique, strong current and earthquakes.

1876, July 7th—Earthquake and the Palermo-Prizzi line disturbed.—Trans. Seis. Soc., Vol. XV. p. 137-138.

In the Journals of the Society of Telegraph Engineers there are many papers and notes on the subject of Earth Currents, and reference is made to these in connection with Earthquakes and Volcanic eruptions.—Vol. II. p. 108.

Newspapers reported an earthquake in the North of England between 6 and 7 p.m. on March 17th, 1871. At Preston 11.5 p.m. Hexham 11.15 p.m. Also felt north of Dumfries. Felt in the Atlantic cables at 0.30 a.m. on the 18th and great irregularites for the next 7 hours. Actual records are given.

December 15th, 1872.—Severe earthquake on the Scinde Frontier. Many lives lost. During the latter part of the evening of the 14th the land lines between Valentia and London had to be looped, the currents being unusually strong.

January 12th, 1873, 1.49 p.m.—Shock of earthquake in Cairo. The land lines between Valentia and London were so disturbed that from 10.35 p.m. on the 11th to 12. 35 a.m. on the 12th they had to be looped.

9th-12th January, 1873.—Great eruption of Skaptar Yokul, in Iceland. Telegraphic lines were influenced on the 9th. Currents on the 10th. Deflection on the 10th, and up to 12.35 a.m. on the 12th.

p. 116:—Mr. G.K. Winter, writing "On Earth Currents," etc., tells us that Mr. Varley says that, in 1864, whilst Mr. Deacon

was testing 120 miles of cable in a tank, an earthquake was felt. The galvanometer needle swung 90°. On this date, Oct. 6th, 1863 (?) 3.25 a.m., Mr. Ellis saw a star move in the field of his telescope. The tilting of the tank, however, Mr. Varley remarks may have been sufficient to produce the momentary current.

p. 117 :—Mr. W. E. Ayrton says that from tests made on the 10th, 11th, and 12th February, 1871, it appears that there were strong currents through the telegraph lines in India, from Dacca to Agra, &c. A day or two after there was an earthquake.

p. 432 :—Mr. James Graves writes :—Valentia, November 26th, 1873.

1.15 a.m.—London complaining of deflections, etc.

1.28 a.m.—Have been 17 min. over the message.

6 a.m.—Have had to work very steady all morning.

At Pau, Basses Pyrenees, on November 20th, between 4 and 5 a.m. there was a strong earthquake.

Vol. X. p. 74 :—At Kew and Greenwich it is observed that electrometer records are not affected at times of magnetic storms which are accompanied by active earth currents.

Vol. XIII. p. 603 :—Mr. E. O. Walker, writing on "Earth Currents in India," remarks that "Earthquakes and eruptions of volcanoes as far distant as Sicily and Java affect earth currents in India." He, however, does not give examples.

In Vol. XIII., Mr. Walker again repeats the opinion that "Earthquakes and Volcanoes as far distant as Sicily and Java affect earth currents in India, sometimes by intensifying the normal current, sometimes by causing abnormal reversals, and, considered together with magnetic and electrical phenomena, appear to be caused by forces exterior to the earth."

A connection made with the hot sulphur springs at Aruli, in the Ratuagiri district, showed nothing more than the usual current.

However earth plates are located, they show the same general

phenomena, even if the plates are laid on the surface or held in the hand. Earth currents are therefore due to a force outside the earth. Perturbations are observed sooner at stations eastwards.

In Japan earth currents have been automatically recorded by an apparatus designed by the late Prof. Shida. Through the kindness of the Telegraph Department, many of the records of 1887 were placed at my disposal and I have compared the same with the earthquake records.

One of the lines runs approximately 60 miles N.E. to Mito and the other 100 miles N.W. to Komoro.

The former shows a maximum of about +.1 mil. amp. between 1 and 2 pm. and latter about +.1 mil. amp. at noon.

Many earthquakes have occurred about the midday maximum. A few at the minima. There have been many days of violent disturbance, as on Oct. 7th, 8th, and 9th, but no earthquakes, whilst on the contrary there have been earthquakes and no recorded electrical disturbance. Now and then earthquakes and electrical disturbances have occurred about the same time, and considering the frequency of both phenomenon it would have been contrary to the laws of chance if this had been otherwise. The disturbances which have apparently coincided with earthquakes have not been greater than those of continual occurrence on the lines. Altogether about 100 earthquakes were compared, with the result that no decided connection between them and earth currents was traceable.

If an earthquake was accompanied by an electrical discharge which only raised the potential at one end of a line, it is reasonable to suppose that a variation in current should result, but if a similar rise in potential occurred at either end of the lines described, simultaneously, it is hardly reasonable to expect any abnormal fluctuations in the records. The absence of currents in the telegraph lines of Japan at the time of earthquakes, therefore by no means makes it certain that Earthquakes are unaccompanied by electrical disturbance.

5.—EARTH CURRENTS IN VOLCANIC COUNTRIES AS COMPARED WITH NON-VOLCANIC COUNTRIES.

As to whether earth currents are more or less pronounced in volcanic countries as compared with non-volcanic countries but little information has been obtained. Mr. W. B. Mason, formerly of the Telegraph Department in Japan, has told us that the lines in this country are not interfered with to such an extent by abnormal currents as they are in England.

Assuming for instance that Mr. Mason's observation is confirmed, can it be assumed that earth currents are in any way related to a subterranean distribution of potential? For example, are surfaces of equal potential beneath Japan flatter or more uniform than beneath a country like England?

6.—OBSERVATIONS AT HOT SPRINGS AND VOLCANOES.

If subterranean chemical and mechanical activity results in the development of electricity, it would appear that the water issuing from hot springs or the steam at volcanoes ought to show, relatively to a neighbouring non-conducting medium, a greater difference in potential than that between two equally distant points on the surface, neither of which had any immediate connection with a subterranean source.

Experiments, which at first sight apparently have a bearing on this question, have been made at many hot springs at Yumoto, Miyanoshita, Kowakidani, Ojigoku, and Ashinoyu.

The instrument employed (no other being obtainable) was a form of Lippmann's electrometer, which before and after each set of experiments was compared with a Cu Fe and a Sn Pb element in water,—the former having an E.M.F. of .149 volts and the latter .075 volts.

As an illustration of the experiments, an example is taken from Ashinoyu, where the water is hot, acid, and sulphurous.

Connecting the Lippmann with the lead-tin element, before and after the experiments, the average movement of the bubble was through 19 divisions of the scale.

The lead-tin element was then removed, and by means of an insulated cable with platinum terminals, the Lippmann was connected with the hot water and the earth. When the earth was a few yards distant from the hot water the deflection was 66: When it was 60 or more yards distant the deflection was 133. The effect increased as the distance between the terminals increased. In one case the movement of the bubble was therefore 3.5 times that produced by the lead-tin element, and in the other case it was 7 times.

When the platinum terminals were both in the same spring or in neighbouring springs no deflections occurred. In almost all cases the earth was positive or like the tin.

On descending from Ashinoyu to near sea level, springs at other places, although equally hot, but chemically different, the deflections observed became less and less, until at Tonosawa near the foot of the pass, they were only .1 to .9 of the lead tin element.

In Tokio, the earth, relatively to the water in a well, say 20 yards distant, was in the same units .5 to .75 positive.

When it rained, until it may be assumed a wet connection was formed beneath the water in the well and the earth terminal, the bubble ran back to zero.

Remembering the nature of the instrument which was employed, it would seem that these observations, rather than showing that the waters at certain hot springs had a potential relatively to the earth 10 or 15 times greater than the superficial well water in Tokio similarly compared, showed that the waters were chemically different.

7.—VARIATIONS IN POTENTIAL BETWEEN WATER BEARING STRATA AND THE SUPERINCUMBENT SURFACE.

For more than 100 days I have taken a continuous photographic record of the difference in potential of the water in a well about 30 feet in depth, and a point on the surface of the earth about 20 yards distant from the mouth of the well.

The electrometer used was by Mascart, and the quadrants

were equally charged from a battery of 50 Water-Daniells. 1 Daniells cell usually caused the spot of light to move 4 or 5 mm. on the scale, and the instrument was therefore not capable of measuring less than half a volt.

Dr. C. G. Knott roughly measured the earth resistance between the surface plate and the well as being about 18,000 ohms. On the day this was made, the earth current gave .32 Daniell, whilst a Pt Cu cell gave .25 Daniell.

The assumption in these experiments was that the water bearing strata would usually be at a constant potential, but at the time of an earthquake this relatively to the surface might experience a sudden change.

At the time of 3 small earthquakes such changes to the extent of 2 or 3 volts were apparently recorded on the photographic plates.

From what is said in the next section it will be seen that these movements may have been due to the mechanical shaking.

8.—VARIATIONS IN POTENTIAL BETWEEN THE EARTH AND THE ATMOSPHERE AT THE TIME OF EARTHQUAKES.

In Trans. Seis. Soc. Vol. XV. and in the Eleventh Report to the British Association (1891), it was shown that decided irregularities had occurred in the photographic records of atmospheric electricity at the time of strong local earthquakes. Subsequent investigations have, however, shown that the Mascart electrometers as used in these and in the previous experiments, unless the platinum wire dipping in the vessel of sulphuric acid is often washed, seem to gradually lose their sensibility. It is, therefore, not unlikely that the recorded movements were the result of mechanical disturbance.

9.—EARTHQUAKES AND RAIN.

If earthquakes are connected in any way with differences in potential between the surface of the Earth and points in its interior at no great distance from its surface, inas-

much as such differences would be less during wet seasons than when the surface was dry, it might follow that the waves on a curve of seismic intensity might correspond with the depressions in the curves of annual rainfall.

Such comparisons have been made.

1.—For all Japan.

2.—For special districts.

3.—For earthquakes which originate beneath the land.

The result of the comparisons shows that in some years earthquakes have been frequent during a rainy season, while in other years they have been few.

The investigation, however, has no bearing on the supposition that considerable differences in potential may be brought about in regions deep beneath the surface.

CONCLUSION.

Although in this and other papers I have brought together a considerable number of observations that would lead us to believe that there might be a connection between earthquake and magnetic and electric phenomena; that hypotheses have been formulated to assist in the conception of the possibility of such connection; that a variety of experiments and investigations have been made to test whether earthquakes were preceded, accompanied, or followed by magnetic or electric phenomena, the results obtained do not guarantee the existence of such connections.

It does not seem likely that earthquakes can result from electric discharges, and it has not yet been proved that they give rise to electric phenomena. When they have resulted in the displacement of large masses of rocky strata, as happened in 1891 in Central Japan, slight local changes in magnetic curves have resulted, but beyond this and effects due to the mechanical shaking of earth plates, our certain knowledge is exceedingly small.