Seismological Investigations.—Twelfth Report of the Committee, consisting of Professor H. H. TURNER (*Chairman*), Dr. J. MILNE (*Secretary*), Lord KELVIN, Dr. T. G. BONNEY, Mr. C. VERNON BOYS, Sir GEORGE DARWIN, Mr. HORACE DARWIN, Major L. DARWIN, Professor J. A. EWING, Dr. R. T. GLAZEBROOK, Mr. M. H. GRAY, Professor J. W. JUDD, Professor C. G. KNOTT, Professor R. MELDOLA, Mr. R. D. OLDHAM, Professor J. PERRY, Mr. W. E. PLUMMER, Professor J. H. POYNTING, Mr. CLEMENT REID, *and* Mr. NELSON RICHARDSON. (*Drawn up by the Secretary.*)

[PLATE I.]

CONTENTS.

I. *General Notes on Stations and Registers.*

THE registers issued during the past year are Circulars Nos. 14 and 15. They refer to Shide, Kew, Bidston, Edinburgh, Paisley, Victoria (B.C.), Alipore, Bombay, Kodaikânal, Batavia, Cairo, San Fernando, Cape of Good Hope, Ponta Delgada (Azores), Toronto, Pilar, Beirût, Baltimore, Trinidad, Honolulu, Perth (W.A.), Christchurch (New Zealand), Mauritius.

Records have not yet been received from Melbourne, Sydney, and Arequipa ; while registers from Wellington, Philadelphia, and Mexico should be brought up to date. The Seismological Committee of the British Association would be greatly indebted to the Directors of observatories at these places if they would kindly forward copies of their observations.

Some time ago a Milne seismograph, which records on a band

2 inches wide, was sent to F. Bareda Y. Asma, Esq., Lima, Peru. This was for the use of the Geographical Society. This year a two-component instrument, recording on a cylinder moving at the rate of 25 cm. per hour, was forwarded to W. G. Davis, Esq., Director of the Meteorological Department, Buenos Ayres. Its number is 49. Two instruments are being constructed for the Public Works Department, Cairo. The intention is to instal one of them at Khartoum and the other near the Victoria Nyanza. We understand that an instrument has been ordered for the Government of South Australia.

Mr. Richard Cooke, The Croft, Detling, Maidstone, has again kindly sent 1*l.* 1*s.* for the support of seismological research.

At a Committee meeting held on February 21, Professor J. W. Judd expressed a strong wish to retire from the office of chairman, which office he had held for nine years. The announcement was naturally received with regret, and a vote of thanks was accorded to Professor Judd for his valuable services. Professor H. H. Turner has kindly consented to take over the vacant position.

The office accommodation at Shide has been increased, and has been seen by the President and several members of your Committee. Mr. H. C. O'Neill joined me as an assistant on March 11, since which time he has been daily attending to the instruments and the regular routine work. I also receive assistance from Messrs. S. Hirota and J. H. Burgess, who, as you are aware, have worked at this observatory since its establishment.

Correspondence, which is frequently of a descriptive nature and requires photographic and other illustrations, has naturally increased with the growth in number of stations and the increasing interest in earthquake phenomena. Material has been supplied to the Committee connected with the Carnegie Institute investigating the San Francisco earthquake, to the Central Bureau of the International Seismological Association, and to many others.

II. *The Situations of Stations.*

Continued from 'British Association Reports,' 1905, p. 84, and 1906, p. 93.

Pilar, Argentina.

On January 20, 1905, the seismograph was dismounted in Cordoba and removed to Pilar, our new magnetic station, lat. 31° 40′ and 4h. 15·4m. W. of Greenwich. A special building was erected for the seismograph and Mascart's electrometer. The building is of brick, with cemented floors and ventilation coming through the floor and passing through the roof, with two windows on opposite sides of the building. The pier on which the seismograph rests is built of masonry, with its foundations extending to a depth of 1·5 metre below the floor. The ground is compact alluvial deposit. The building is situated about 100 metres from the Rio Segundo, that is, the river Segundo. In summer there is frequently a large volume of water, but in winter the river is practically dry.

The instrument was installed on February 1, 1905, but the masonry was not considered sufficiently settled to allow of trustworthy registers from the instrument till the end of the month, so that the records of 1905 begin on March 1. The photographic record, however, shows no well-defined movement during the month of February. The period of the boom oscillations was kept constant from the month of February till June 22, at 17 seconds, the same as formerly used in Cordoba, giving a sensibility of 0″·56. On November 2 this was increased to 16 seconds, with a sensibility of 0″·50 to one millimetre of displacement of the outer end of the boom.

W. G. Davis, *Director.*

Colombo, Ceylon (Observatory at the Technical College).

Lat. 6° 54′ N.; long. 79° 51′ E.; alt. 13 feet above mean sea-level.

Foundation.—A brick-in-cement pier built on a cement-concrete base rising from a bed of laterite.

Topographical Situation.—The Observatory is situated on low ground, quite close to a canal, about 50 feet from the bank of it. There is a lake about 150 yards away towards the south-west, with which the canal communicates direct. The sea is about a mile distant (south-west) from the Observatory. The canal above mentioned is on the north of the Observatory.

Geological Structure.—The ground surrounding the Observatory to a considerable distance is alluvium with outcropping laterite.

Rating.—The rating of the time-keeper attached to the instrument is done by comparison with the chronometer of the Master Attendant, Colombo Harbour, at intervals of two to three days, by means of a portable time-keeper carried backwards and forwards in a locked box. Periodic time of instrument varied between 18 seconds and 15 seconds. During the period August to December the periodic time did not fall below 17 seconds, and for the months of September and October the periodic time was nearly 18 seconds.

E. HUMAN, *Superintendent.*

III. *Photographic Record-receivers.*

If two similar and similarly adjusted seismographs are installed on sites which are geologically and topographically different it is to be expected that the records they yield will show certain differences. If, for example, we compare the seismograms obtained at a station on rock with one on alluvium we find that at the former, within a given period, more records have been obtained, and earlier times of commencement, than at the latter.[1] The probable explanation of this is that thick beds of alluvium, in consequence of their non-elastic nature, do not transmit the waves of small amplitude which constitute small earthquakes and the preliminary tremors of larger disturbances.

Another condition on which the recording of very minute waves is dependent, and which does not hitherto appear to have been recognised, is the speed of the film on which the record is received.

In connection with the Milne horizontal pendulums adopted by the British Association, two types of recording surfaces are now employed. In one the photographic film moves beneath a slit about 0·25 mm. in width at the rate of 60 mm. per hour. In the other the photographic surface passes beneath a similar slit at a little over four times that rate.[2] In the first type of receiver the paper as it passes the slit is exposed to light for fifteen seconds, whilst in the second the exposure is between three and four seconds. Experiment shows that the line obtained from the long exposure may be double the breadth of that from the short exposure. From this it would seem that minute tremors with a short period which would show as deviations of the narrow line might be eclipsed if the same became broadened by halation. This, however, would not be the case if the tremors had a very long period.

This probably explains the observation that earlier commencements are more frequently noticed on a rapidly moving surface than on one which moves more slowly. For example, for the year ending June 1906, for a series of sixty-one disturbances, a pendulum, at Shide recording on a quickly moving surface was on forty occasions from one to six minutes in advance

[1] See *Brit. Assoc. Rep.*, 1902, p. 74, and 1903, p. 82. [2] *Ibid.*, 1904.

of a similar and similarly installed pendulum recording on a slowly moving surface. With very large earthquakes in which the preliminary tremors have comparatively large amplitudes, differences of this nature are not observable. Although attention is only called to the photographic recording apparatus used with seismographs, it is evident that the character of the results obtained from other instruments may also to some degree be dependent upon the speed of recording surfaces.

IV. *Origins and Relationships of Large Earthquakes in* 1906.

The number of entries in the Shide register for 1906 is 207. Out of this number ninety-two may be regarded as megaseismic in character. This number is distinctly above the average. On the accompanying map the origins of seventy-one of these are shown, the districts of greatest activity being *E* and *F*. The display of activity, however, to which public attention has been chiefly directed, occurred on the western shores of North and South America. On January 31 we had the Colombian earthquake, the origin of which was apparently sub-oceanic off the mouth of the Esmeralda River. This convulsion, which led to the interruption of several submarine cables, was followed by shocks in the Antilles. On April 4 a disastrous shaking took place in the Kangra Valley, in North-West India. Ten days later the Formosan earthquake occurred, which ruined 5,556 houses. On April 18 San Francisco was destroyed. Notwithstanding the intensity of the initial impulse, which, we are told, sent earth-waves twice round our world, it is astonishing how very little damage was done merely by the shaking of the ground. The greatest destruction was occasioned by fire. The origin of this disturbance was along lines of faults, which can be traced for distances of several hundreds of miles. The strike of these faults is apparently fairly parallel to the coast line, or from N.N.W. to S.S.E. The seismograms obtained at distant stations lying to the east or west of California, or at right angles to the fault, were very pronounced, whilst at Cordova, in South America, records were extremely small. Exactly the opposite occurred in the Jamaica earthquake which took place on June 14. In this case the strike of the fault or faults was east to west, and the seismograms in Europe, *i.e.*, to the east of Jamaica, were extremely small. On August 17 Valparaiso and the towns in its neighbourhood were reduced to ruin. In Greenwich mean time the Valparaiso earthquake occurred at 0h. 41m. 2s. Thirty-three minutes before this, or at 0h. 8m., or 0h. 11m. G.M.T., a very large earthquake took place beneath the North Pacific to the north of the Sandwich Islands. The time taken for the second phase of this shock to travel from its origin to Valparaiso, a distance of 122°, would be about 31 minutes. This time-interval suggests at least three possibilities: (*a*) The earth-waves from the North Pacific may have released a state of seismic strain in Chili; or (*b*) the earthquake in this latter country may represent an effort to establish a dynamical counterbalance consequent on a molar displacement in the North Pacific; or (*c*) the two disturbances were due to some common influence.

The fact that large earthquakes so frequently occur in pairs or groups precludes the idea that these short intervals between megaseismic effects are merely matters of chance.

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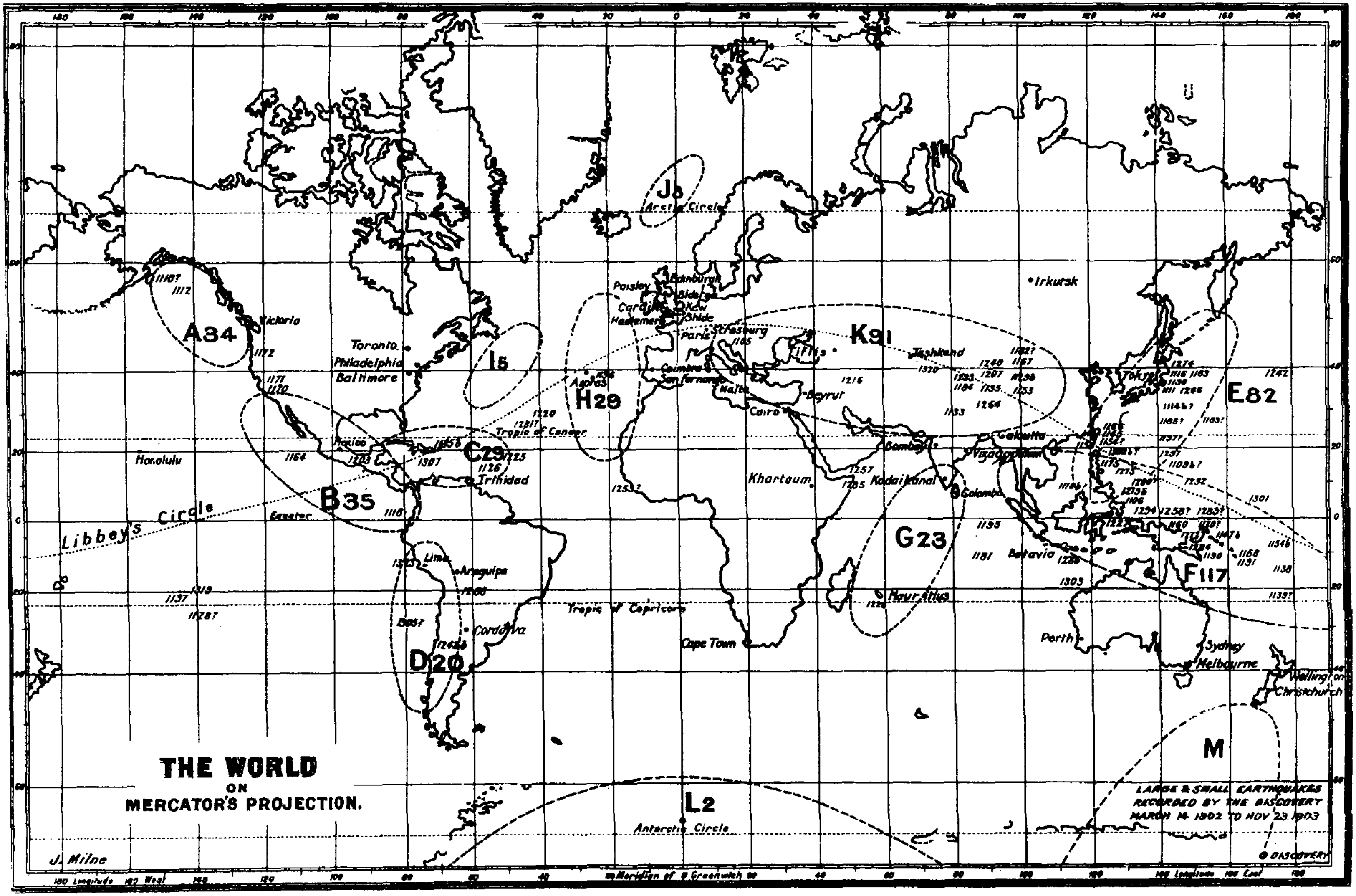
Origins for 1906 are indicated by their B.A. Shide Register number. Earthquake districts are indicated A, B, C, &c., and the number of Earthquakes since 1899 which originated from these is expressed in large numerals. The two arcs from England to the Pacific Coast of America refer to the Note by Mr. R. D. Oldham in this Report.



Illustrating the Report on Seismological Investigations.

The epicentre for the first shock has been given at 40° N.L. and 170° or 180° E.L. (Milne), 30° N. and 170° E. (Oldham), and 50° N. and 170° E. (Ōmori).

V. *On the Apparently Luminous Effects from certain Rocks.*

The object of the following note is to show that at certain times surfaces of chalk or clay slate as they exist in mines and quarries give rise to continuous or sudden radiations which make an impression similar to that produced by light upon a photographic film. Various motives led to the experiments. Accounts of luminosity in the heavens or on hills at the time of large earthquakes are common. One of the last occasions upon which phenomena of this nature were observed was at the time of the Valparaiso earthquake, August 17, 1906. Mr. W. G. Davis, Director of the Meteorological Survey of Argentina, tells me that as seen by Captain Taylor from the deck of the R.M.S. 'Orissa,' lying fifty metres from the wharf at Valparaiso, there appeared upon the hills at a height of about 500 metres waves of light. These waves, which are compared with chain lightning, extended as far as the eye could reach, and lasted during the first shock, of nearly two minutes.

On these occasions strong earth-currents have affected the working of land lines, and needles of galvanometers have been disturbed. In Tokio the writer found that an electrometer, whether arranged to record the difference of potential between the earth and the atmosphere or between the surface of the ground and water-bearing strata at a depth of 30 feet, would from time to time suffer large displacements. The times at which certain of these were recorded agreed with the times of local earthquakes, and might therefore be regarded as the result of a mechanical disturbance. When these observations were made teleseismic unfelt movements had not yet been recorded, and it was therefore impossible to determine whether such disturbances had any true relationship with many unexplained electrometer perturbations. Now we know that unfelt earth-movements may be accompanied by movements of magnetic needles and disturbances in the records from electrometers. These and kindred observations suggested the possibility that a megaseismic collapse might not only produce mechanical disturbances through and over the world, but that part of the initial energy at the centrum might be converted into another form of energy which might be transmitted to all parts of the world simultaneously. When a territory equal in area to the British Islands is shattered to such a depth that the homogeneous nucleus of our earth is caused to vibrate, as we have indicated, a local transformation of energy in the form of light has occasionally been observed. But we have no definite information as to the distance this or its equivalent may be transmitted. The observation that from time to time a quarry in the Isle of Wight, known as Pan Chalk Pit, which I occasionally passed at night, appeared to be luminous also, suggested the possibility of hypogenic activities, giving evidence of their existence in the form of light. The pit or quarry faces north. In winter it is not reached by the sun. Its glowings, which apparently rise and fall in intensity, are most noticeable after a dull damp day.

To determine whether these appearances were real, and whether they might be connected with other phenomena, I made, with the permission of Mr. J. L. Warsap, the following experiments. At the end of a chamber twenty yards from the mouth of a tunnel driven into the chalk, a hole about two feet square was excavated. Into this a box with a light-proof door was cemented. In this box a Richard self-recording thermometer drum covered with a Kodak bromide paper was placed. The drum, which was entirely made of brass, revolved at the rate of 40 millimetres per day. Between it and the chalk face, distant about half an inch, there was a sheet of zinc in which were two round holes respectively about an eighth and a quarter inch in diameter. One was below the other, and lower still there was a vertical slit. As the drum turned, the paper was exposed to the chalk through these openings. Experiments were continued for four months, ending May 8, 1903. During that interval photographic impressions were only obtained on three or four occasions. These were in the form of black discs, possibly representing the holes and straight lines for the slit. The first series read as follows: February 6, 6.30 P.M., 8.54 P.M.; February 7, 0.30 A.M. and 2.54 A.M. Nothing in the nature of a glow extending over several hours or anything coinciding in time with a large earthquake was recorded. It was, however, interesting to note that photographic effects had been obtained in a place and under conditions where it is difficult to imagine that they had been the result of artificially produced light.

For various reasons these experiments were not again taken up until August 19, 1906. On that date a piece of apparatus in many respects similar to that used in 1903 was put up in a dark chamber, cut in the chalk inside the tunnel leading to the Pan Chalk Pit. The chief differences between the new and the old installations were as follows: In the new apparatus the cylinder carrying the paper moved at the rate of 90 mm. per day. This shortened the exposure of the film as it passed before the holes in the zinc plate between it and the chalk face. The distance between the film and this plate was reduced to one-eighth inch, whilst an aluminium rim forming the bottom of the brass drum revolved inside a horizontal slit cut in the plate. The rim was at a distance not greater than one sixteenth inch from the top and bottom of the slit.

The drum stood inside a wooden case outside which at the distance of an inch was a second case. The dimensions and form of the holes in the zinc sheet which formed the end of the inner box were as follows: A round hole one-eighth inch in diameter, a triangular hole with half-inch sides vertically below the round one, and below this a square hole with sides of one inch. The holes were about an inch apart, and underneath the square hole was the slit, cut to free the rim of the drum.

The movement of a small electric lamp round the face and sides of the box produced no effect on the paper inside, and hence it may be inferred that the box was light-proof. A self-recording thermometer and a hygrometer between November 5 and 19 showed that the temperature and the moisture in the chamber were practically constant.

A similar piece of apparatus was, through the kindness of Mr. B. Angwin and Mr. J. G. Lawn, placed in the King Edward Mine, Camborne, Cornwall, at a depth of 160 feet. The rock was damp, as in Pan Chalk Pit. At both places cakes of calcium chloride were used to dry the atmosphere, but I cannot say they were effective. For about three months papers were exposed simultaneously with those at Shide, and the results were compared. Another piece of apparatus was set facing the chalk in a light-proof hut in White Pit Lane, between Shide and Carisbrooke. The drum was inclosed in a box (also light-proof) inside the hut. Its rate of running was only a little over a half that of the instruments at Pan Chalk Pit and Camborne.

In each case the drums turned once a week, in which interval they used one sheet of bromide paper.

Amongst various control experiments which were made I may mention the following :—

I. Two pieces of chalk, one of which had been soaked for several hours in water, were placed over a piece of rapid bromide paper. Between the paper and the chalk there was an air space of about one millimetre. At the end of forty hours development showed that no effect of any description had been produced. Each piece of chalk had a surface of about four square inches.

II. For two weeks the instrument from the Pan Chalk Pit was mounted in my observatory, where a plastered brick wall took the place of the natural chalk face. To approximate to the conditions in the pit, inside the covering case a bowl of water and a wet sponge were placed. The developed films did not show any trace of photographic action. The ideas of making these last experiments arose from communications with the manager of the Kodak works at Harrow, who pointed out that effects had been produced upon photographic surfaces inclosed in dark slides made from aluminium, and also in apparatus where movable parts of aluminium and zinc were used. The drums used at Shide and at Camborne were made of brass and aluminium, and they passed very closely to a fixed sheet of zinc. But I have only got photographic effects when the apparatus was underground in the places described.

III. Several pieces of bromide paper have been inclosed in black envelopes and placed against the face of the chalk in the instrument chamber at the Pan Pit. After a week's contact there was no trace of photographic action on the film when it had been developed.

IV. Several pieces of bromide paper have been placed in envelopes which had a thin glass window which touched the chalk. After a week's exposure the paper opposite the window was sometimes blackened.

More Important Observations.

Pan Chalk Pit.

November 12 *to* 19, 1906.—12th, 14h. to 14th, 17h. 45m., strong singeings. At this time it was foggy and frosty. Intermittent singeings 30m. to 3h. apart.

November 19 *to* 26.—19th, 10h., to 21st, 10h., strong singeings. Weather frosty, finishing with rain. Up to 25th slight intermittent singeings. During this period there were many spots; one group agrees with a slight earthquake on 21st at 23h. 57m.

November 26 *to December* 3.—26th to 28th, spots fairly numerous. Singeings strong November 26th, 16h., to 27th, 6h. Weather dull and fine. Spots also numerous December, 3h. to 20h., and singeings (strong). Slight rain and stormy.

Camborne.

November 13 *to* 19, 1906.—No record, as paper had been exposed to light; still on it three parallel lines can be traced, made up apparently of a series of spots bounded by a luminous band.

November 19 *to* 24.—Parallel bands reproduced, but the dotted lines are broken. On 19th, 10h. to 20h., and 23rd, 10h., singeings; 19th, strongly marked.

November 24 *to December* 1.—Upper and lower luminous bands surrounding broken dotted line.

December 1 *to* 8.—Luminous bands and broken lines continue. Strong singeings December 1, 16h., to 3rd, 10h.; 4th, 10h.; 8th, 10h. Weather foggy and stormy.

December 10 *to* 17.—10th, 13h., 12th, 10h., heavy singeings; 13th, 17h., to 15th, 9h. 30m., heavy singeings. Luminous band opposite top small hole 13th A.M. to 16th noon.

December 24 *to* 31.—24th noon to 19h., intermittent singeings; 25th, 0h., to 29th, 15h., same; 29th, 21h., to 30th, 15h., same. A few spots.

December 31 *to January* 7, 1907.—31st, 12h., to January 1st, 6h., occasional singeings which continue at intervals of several hours up to January 3. January 4th, 3h., to 5th, 11h., intermittent singeings, only one or two spots.

January 22 *to* 29.—22nd to 28th, heavy singeings, most of time weather cold and frosty. Running along the top of singeings is a very fine line.

January 29 *to February* 5.—February 1st, 2h., slight singeings to 11h.

March 19 *to* 25.—*19th, 10h., 16h.* slight singeings.

March 25 *to April* 1.—Mere trace of singeings, 30th, 16h.

April 1 *to* 8.—1st, 11 A.M., slight singeings repeated at long intervals during week.

April 8 *to* 15.—Neither singeings, spots, nor bands. For most part weather showery and dull.

April 15 *to* 22.—Very slight singeings.

April 22 *to* 29.—Clear sheet.

December 8 *to* 15.—8th, 14h., luminous band, dotted lines; 9th to 10th, strong singeings, and 13th to 14th; 11th, very large spot 10h. 30m., 15 mm. diameter.

December 18 *to* 21.—Luminous bands. No records until March 18.

March 18 *to* 24, *1907.—Bands very* faint.

March 23 *to* 28.—Two faint bands.

April 2 *to* 6.—2nd to 5th, luminous band with a chain-like pattern. Slight singeings 3rd, 12h., at intervals to 5th, 12h. From 3rd, 12h., to 4th, 12h., groups of large spots.

April 6 *to* 11.—From 6th to 10th intermittent singeings.

April 11 *to* 17.—12th to 17th, bands very faint.

April 17 *to* 23.—Two dark bands. 18th to 19th, slight singeings.

The Results.

The sheets of paper were changed once a week and were always found to be very damp. When they were developed, certain sheets were perfectly clear whilst others were partly or entirely marked with dark bands, black lines, round black spots, or semicircular spots along the lower edges. These latter, from their appearance of having been burnt, have been called singeings.

I. *Dark Bands.*—Those have not been very numerous, but were found four times out of twenty-nine sheets from Shide, eleven times out of twelve sheets from Camborne. They were never found on fourteen sheets from White Pit Lane. On removing the instrument at the latter place it was found that the zinc plate had so far buckled that the bromide paper may have been a quarter of an inch from the chalk. Those from Pan Chalk Pit *were about one inch in width, being darker in the centre than near* their edges. They occurred opposite the triangular hole, the edges of which touched the chalk. Those from Camborne varied much in character. In certain cases we appear to have had at least three bands, apparently coinciding with the three holes in the zinc plate interposed between the film and the rock surface. In some of these bands there were hard black lines broken along their length and made up of black spots.

II. *Black Spots.*—These vary in diameter from 1 mm. to 8 mm. In the centres of some of these there is a small white or brownish spot. As pointed out by Mr. W. H. Bullock of Newport, these closely resemble the spots produced when a piece of bromide paper is placed between the poles of an induction coil. Sometimes they were very numerous, and at other times only one, perhaps, was found on a sheet.

III. *Singeings.*—These occur on the lower edge of the paper where the brass cylinder joins the aluminium ring. They are sometimes continuous, or they may occur at intervals of half-an-hour to several hours on the length of a whole sheet. At other times only a group of two or three can be found during the entire week.

If we attach the secondary terminals of an induction coil, one to the zinc sheet and the other to the drum, bands, spots, and singeings closely simulating those recorded in the chalk pit may be obtained.

Between August 19, 1906, and January 29, 1907, sixty-three large and small earthquakes were recorded at Shide. Out of these only ten nearly coincided with the time of occurrence of spots upon the paper. As at times the spots were so very numerous, we can only regard these coincidences as accidental. So far as we can see, bands, singeings, and spots occur in any state of the weather, and are therefore not connected with any ordinary meteorological conditions.

Neither is there any distinct evidence that the markings are due to radio-activity. There appears, however, to be a suggestion that the luminosity occasionally seen at Pan Pit may result from a very feeble brush or glow-like electrical discharge. If this be so, it would also account for the bands on the photographic paper, the other markings being due to minute sparks.

If we assume that there are radio-active or electrical emanations of hypogenic origin from our earth, it is difficult to escape from the conclusion that such must have an effect on what we call 'climate,' and hence upon everything which lives upon the surface of the globe.

VI. *Earthquakes and Changes in Latitude.* *By* Professor C. G. Knott.

In the last report Professor Milne continued his interesting comparison of the occurrence of large earthquakes and the movements of the earth's pole. The table he gave seems to call for a further discussion. Milne's idea is to connect the occurrence of the earthquakes with the curvature of the path traced by the projection of the pole on the celestial sphere. But if there is to be any connection of the kind looked for, ought we not rather to consider the deviations from the mean value of the curvature or deflection (to use Milne's terminology) than the deflections themselves? For this mean curvature per tenth year we may consider to be due to some steadily acting dynamical cause, such as a slight departure from coincidence of the axis of rotation with the principal axis of inertia. From this point of view we should regard small deflections of 5° or 10° as being abnormal equally with large deflections of 60° or 70°. Hence the earthquake frequency should be compared with the deviations of the deflections from the mean, which for the whole set of observations is almost exactly 30·5. I shall take the two groups as given in the last report together. By subtracting the mean deflection from the average deflection in each range we obtain what I shall call deviations from mean curvature. These form the first and fourth columns in the following table, the second and fifth containing the number of times this particular average deviation occurred; while the third and sixth columns contain the average number of earthquakes corresponding with the deviations.

Deviations from Mean	Number of Occurrences	Average Number of Earthquakes	Deviations from Mean	Number of Occurrences	Average Number of Earthquakes
−28	1	18	+ 2	17	12
−23	8	20·1	+ 7	16	12·5
−18	10	6·5	+12	10	11
−13	7	7·4	+17	8	17
− 8	15	9·7	+22	6	20
− 3	23	13·9	+37	2	21
			+37·3	5	24

The number of occurrences are given by way of contrast. It is obvious that they follow roughly the well-known law of grouping about a mean, the maximum being in the neighbourhood of zero deviation or mean deflection. But it is quite otherwise with the earthquake numbers. If there were no connection, direct or indirect, between the two phenomena, the earthquake numbers would be fairly constant throughout. There seems to be, however, a tendency toward greater values for higher deviations. For deviations up to +12 and −13 the averages total 66·5, or an average of 11·1. For deviations greater than these limits the averages total 126·6, or an average of 18·1. This conclusion lends a certain amount of support to Milne's view that there is some connection between the occurrence of large world-shaking earthquakes and the movements of the earth's pole.

The mean curvature of the path of the pole is 30·5 per tenth year, or 305 per annum. Hence the pole will make a complete revolution in 365 × 360/305 days, or 432 days. The value given by Chandler is 427 days. It is well known that a rigid body of the size, figure, and mass of the earth will have a small precessional motion of period—305 days if the axis of the figure is not quite coincident with the axis of diurnal revolution. To explain the large discrepancy between the observed value 427 and the theoretical value 305, Newcomb invoked the influence of elasticity in modifying the period of precessional rotation. His original calculation was admittedly approximate, and Hough [1] has worked out the problem in a more rigorous manner. Taking account of the elasticity only, he finds that the precessional period will have the value 427 days if the effective rigidity of the earth were a little greater than that of steel. Newcomb also pointed out that the mobility of the ocean would have the same effect of lengthening the precessional period. Further, if the effective rigidity of the earth were to diminish all over, the precessional period would be increased. It is not easy to see what would be the immediate effect of either a local diminution of rigidity or a local yielding to stresses such as takes place when an earthquake is originated. But it is at all events not unreasonable that some effect will be produced. This is probably the direction in which we must look for the connection imagined by Milne.

[1] 'Rotation of an Elastic Spheroid,' *Phil. Trans.*, vol. clxxxvii. A, 1896.

VII. *Note on the Duration of the First Preliminary Tremor in the San Francisco and Colombian Earthquakes. By* R. D. OLDHAM.

The great earthquakes of Colombia, January 31, 1906, and California, April 18, 1906, originated at not very greatly different distances from Western Europe, but reached it by very different wave-paths. The great circles from Shide, plotted on the map, show that in the former case the wave-paths lay under the broadest and deepest part of the Atlantic Ocean, and in the latter under the continent of North America and the continental shelf of the North Atlantic. In studying the records of these two earthquakes I found that there was a marked difference in the interval between the arrival of the first and the second phases of the preliminary tremors, the interval at Shide being 9·9 minutes for a distance of about 77·6 degrees in the Californian, and 11·9 m. for a distance of about 80·7 degrees in the Colombian, records. The difference between these two, viz., 2·0 minutes, is greater than the average, but a comparison of all the records from European observatories, at which these two phases can be recognised in the case of both earthquakes, gives mean intervals of 10·4 and 11·4 minutes for mean distances of 84° and 86° in the case of the Californian and Colombian earthquakes respectively. The difference in interval, corresponding with the difference in distance, is only 0·2 minute, or one-fifth of the observed difference. As these two phases of the record are due to wave-motion of different kinds, transmitted at different rates, through the earth, the difference in interval between their arrival indicates a difference in the ratio between their rates of transmission, and consequently a difference in the constitution of the matter under the North American continent and the North Atlantic Ocean. The exact time of occurrence of the Colombian earthquake being unknown from direct observation, it is not possible to compare the absolute rates of propagation and determine in what this difference consists, but it appears to be too great to be due to any error of record or interpretation, and may be accepted as real.