Seismological Investigations.—Ninth Report of the Committee, consisting of Professor J. W. JUDD (*Chairman*), Mr. J. MILNE (*Secretary*), Lord KELVIN, Professor T. G. BONNEY, Mr. C. V. BOYS, Professor G. H. DARWIN, Mr. HORACE DARWIN, Major L. DARWIN, Professor J. A. EWING, Dr. R. T. GLAZEBROOK, Mr. M. H. GRAY, 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, Mr. NELSON RICHARDSON, *and* Professor H. H. TURNER. (*Drawn up by the Secretary.*)

[PLATES I. AND II.]

CONTENTS.

I. *General Notes on Stations and Registers.*

DURING the past year the registers issued are Circulars Nos. 8 and 9. These refer to Shide, Kew, Bidston, Edinburgh, Paisley, Toronto, Victoria, B.C.; Baltimore, San Fernando, Cairo, Ponta Delgada, Cape of Good Hope, Alipore, Bombay, Kodaikanal, Batavia, Irkutsk, Perth, Mauritius, Trinidad, Tiflis, Christchurch, Wellington, Cordova, and Tokyo. Captain H. G. Lyons, R.E., Director-General of the Survey Department at Cairo, writes that the Abbassia records terminated on December 23, 1903. On the same day they were recommenced at Helwan, long. E. 31° 21′, lat. 29° 52′. At Abbassia, in the delta, the foundations were on sand, and during wet weather may have been disturbed. At Helwan the instrument stands on a limestone pier founded on solid rock.

It is anticipated that an instrument will shortly be installed at Malta.

The multiplication in the number of stations, scattered as they are all over the globe, has led to a great increase in the work of correspondence and reduction which has to be undertaken at Shide. Much of this work might well be done by an assistant under the supervision of the Secretary, leaving the latter more free to devote himself to scientific problems. The Committee consider that the time has arrived when a fund should be established to provide a sufficient income for securing the continuity of the work in the future. Upon such a fund the salary of an assistant would be a principal charge. The Committee are happy to be able to report that Mr. M. H. Gray has very generously given the sum of 1,000*l.* to serve as the nucleus of such a fund, while the Committee on Geophysics of the Carnegie Institution of Washington have also expressed a desire to contribute to the important work which is being carried on at Shide. The Committee are in correspondence with the Executive Committee of the Carnegie Institution, and they trust that donors will come forward to assist in putting the work upon a permanent basis.

It may here be mentioned that Mr. M. H. Gray has already given material support to the station of Shide; his brother, Mr. R. K. Gray, provided the instrument for San Fernando; Mr. Joseph Wharton, of Philadelphia, U.S.A., gave the instrument installed at Strathmore College, near that city; pendulum apparatus was given to Shide by Mr. A. F. Yarrow; the instruments in Hawaii, Victoria, and Mauritius were paid for, or partially paid for, by funds put at the disposal of your Secretary; while the remaining installations were established by institutions or Governments in the countries where they are now working.

II. *On the Comparison of Records from three Milne Horizontal Pendulums at Shide.*

These pendulums and their installations referred to in the following note are described in the British Association Reports, 1902, p. 60, and 1903, p. 81.

Pendulum A is the type instrument, and carries a load of 243 *gms.* It stands on its own pier, records E.W. motion, and its period, like similar instruments in other parts of the world, has been kept at about seventeen seconds.

Pendulums B and C stand on the same pier and swing on the same cast-iron upright. B is parallel to A, and, like it, records E.W. motion. C responds to N.S. motion, but by means of an arm attached to it, similar to the arrangement shown in the British Association Reports for 1902, p. 61, fig. 1, its records are made side by side with those of B. At intervals of several months the loads carried by B and C have been purposely varied, and the object of this note is to show the differences in the results obtained in consequence of such changes. In considering these differences two points not to be overlooked are, first, that only the movements of A and B are comparable; and secondly, that the swinging of B might cause motion in C, and *vice versa.*

The comparisons given in the following table refer to the number of records given during different periods by A, B, and C, and the number of

—	Number of Records			Number of Early Commencements		
December 28, 1902, to April 28, 1903	A	B	C	A	B	C
I. A, p. 17, W. 243 grms.		—			—	
I. B, p. 17, W. 237 ,,	35	35	31	15	12	15
I. C, p. 20, W. 155 ,,		—			—	
April 28 to December 6, 1903						
II. A, p. 17, W. 243 grms.		—			—	
II. B, p. 17, W. 237 ,,	29	40	50	9	12	47
II. C, p. 20, W. 404 ,,		—			—	
December 8, 1903, to May 2, 1904						
III. A, p. 17, W. 243 grms. ,,	22	40	31	8	33	27
III. B, p. 30, W. 394 ,,		—			—	
III. C, p. 20, W. 404 ,,		—			—	

times each of these pendulums commenced to record either sooner than the others or at least simultaneously with one of the others. P=period in seconds, and W=load carried by the booms expressed in grammes.

During the first period the records accord fairly well with what might be expected, the small moment of C accounting for the small number of its records.

In the second period, when the load on C was increased threefold, we find that it gives the largest number of records and the largest number of early commencements. The large increase in the records on B may be due to the influence of C swinging on the same support. In the last period, when B carried a load practically equal to that on C, and had its time of swing increased to thirty seconds, we see that it gave the greatest number of records and also most frequently was disturbed before the others.

Although these records are not strictly comparable, and for the most part only refer to mere thickenings of the photographic trace, they suggest that an increase in load and of period in the type instruments would result in increased sensibility.

III. *Improved Record Receiver for Horizontal Pendulum Seismograph.*

The accompanying illustrations, figs. 1 and 2, show two views of a new seismograph recorder.

The instrument consists of a light brass cylinder, D, 1 metre in circumference and 160 millimetres wide, mounted upon a steel spindle. One of the projecting ends of this spindle has a deep-threaded helix of 6 millimetres pitch cut in it ; this being suitably mounted upon roller bearings, advances the cylinder 6 millimetres for one turn in four hours, by a gear connection with a clock. The bromide paper carried on the cylinder is changed every 3·5 or 4 days.

A cylindrical mirror has been introduced to give a greater concentration of the light on to the boom-plate.

For the time record mark upon the bromide paper a shutter actuated by an electro-magnet is employed, the light being shut off from seven to ten seconds every hour. For this purpose a regulating clock with suitable electric contacts is required. An example of records from the new and old form of receiver is shown in Plate I.

The advantages of the new arrangement are :—

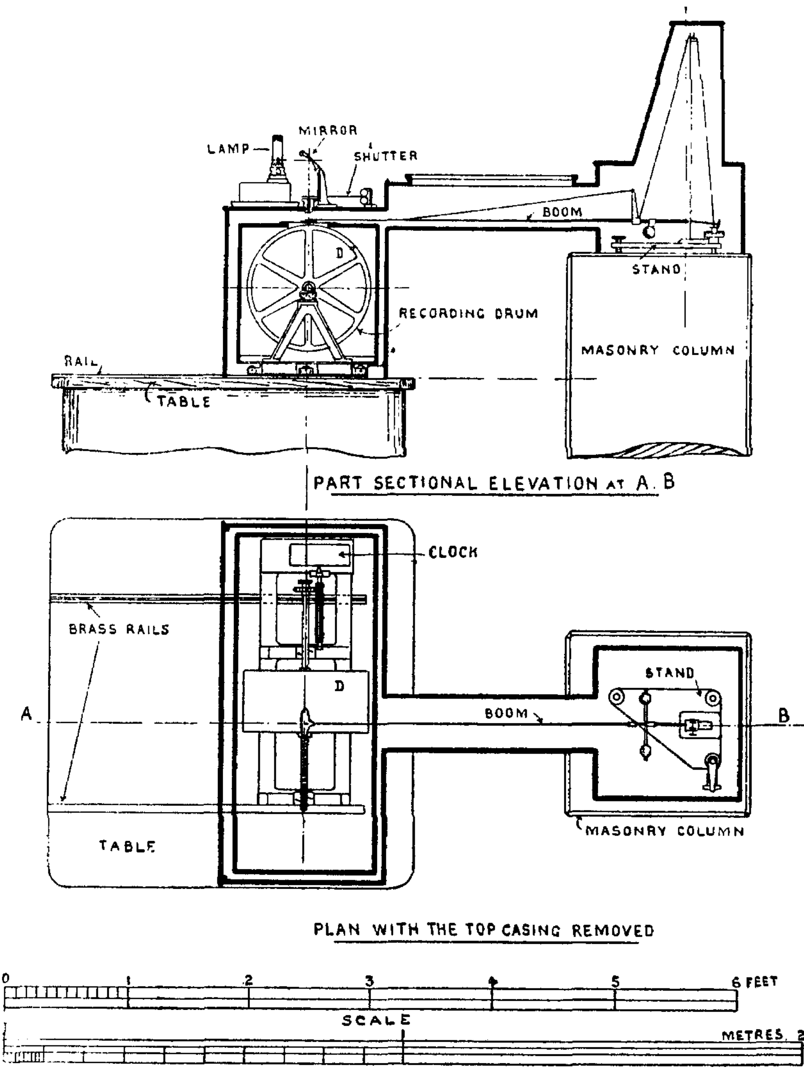
1. Although the paper moves beneath the end of the boom at more than four times the rate (250 millimetres per hour) that it does in the original receiver, only one-half the quantity of paper is used. This implies a large reduction in expense for paper and developer, the latter being applied by a brush.
2. An open diagram is obtained on which wave-periods can be measured.
3. Movements of small amplitude are easily recognised.
4. Records can be quickly inspected and are easily stored.

IV. *The Origins of Large Earthquakes recorded in* 1903 *and since* 1899.

The origins of the large earthquakes recorded in 1903 are indicated by this Shide register number upon the accompanying map, Plate II. In the registers (Circulars 8 and 9) there are 135 entries for this year, whilst on the map only sixty-four origins are indicated, which means that there were about seventy-one earthquakes the materials relating to which were insufficient to enable their origins to be determined. Even with the origins which have been determined, the notes of interrogation attached to numbers on the map indicate that such determinations are accompanied by uncertainty.

Speaking generally, it may be inferred that about 50 per cent. of the

FIGS. 1 AND 2. Milne's Horizontal Pendulum (seismograph) with new recording arrangement.



large earthquakes have disturbed the world's surface as a whole, whilst the remainder have only affected areas equal to those of single continents.

The greatest activity is again along the Libbey Circle (radius 70° and centre 180° E. or W. long., and 60° N. lat.). Marked activity has taken place at the junction of regions E. and F., and in the eastern portion of the E., both of which may be described as regions in which there are intersections of tectonic folds.

Maps corresponding to the one here given can be found in the British Association Reports for 1900, 1902, and 1903.

V. *On International Co-operation for Seismological Research.*

In 1902 the British Government received an official invitation from Germany to take part in a Conference the object of which was to establish an international inquiry about earthquakes. Acting under the advice of a Committee appointed by the Royal Society, the Board of Education appointed Professors G. H. Darwin and J. Milne to represent Great Britain at the proposed Congress, which took place in Strassburg July 23 to 28, 1903. Twenty-five States or countries were represented, but the total number of delegates and guests who were at liberty to take part in the proceedings was 100, out of which sixty-two were Germans. Final results were arrived at by single voices, each country having one vote; thus Great Britain and her colonies, like the German Empire, had each one vote only. France was not officially represented.

The more important results arrived at were as follows :—

A Central Association is to be formed with its headquarters in Strassburg. Each contributing country will be represented by one member of a governing Committee, which elects a President, a Chief for the Central Office, and a General Secretary. The Chief will reside in Strassburg, but it was decided that the President and Secretary should be elected from outside Germany.

The work of the Association would be as follows :—

1. To carry out observations after a common plan.
2. To carry out experiments on important matters.
3. To establish and support observatories.
4. To collect, study, and publish reports or *résumés* of the same.

The cost of this work, including a Secretary's salary, is to be for the first twelve years about 1,000*l.* per annum, twelve years being the duration of the Convention. The contributions to make up this sum are to be apportioned amongst the co-operating States according to their population, the British contribution to be 160*l.* per year. Should Great Britain join the Convention, as it will be necessary to send a representative to the Governing Committee, the total annual outlay will be about 200*l.*

Whilst at Strassburg the British delegates explained that they were in no way empowered to pledge his Majesty's Government, and that they had been informed that their Government would not take action that had not the support of the International Association of Academies. At the last meeting of this Association, held in London May 24 to 30, 1904, the advisability of international co-operation for purposes of seismological research was discussed, with the result that it has been referred for further consideration to the following Committee : Professors A. Schuster (Chairman), Helmert, de Lapparent, Mojsisovics, Agamennone, Karpinski, and T. C. Mendenhall.

The Foreign Office and the Board of Education have been informed of this action.

On April 21, 1904, the Seismological Committee of the Royal Society reported to the Council of that body as follows :—

(1) That this Committee is of opinion that any moderate subsidy likely to be available would be most profitably expended in supporting the seismological work inaugurated by the British Association, and that there is urgent need of such help, which should be a first call on any such funds.

(2) Assuming this need supplied, the Committee would approve the further co-ordination of the work by joining the proposed Association.

VI. *Notes upon Seismological Work in various Countries.*

1. *Austria.*

With the object of recording earthquakes with a local origin, Austria is divided into sixteen districts, each with many observers. Their notes, which are for the most part made without the aid of special instruments, are collected at a local centre. From 120 to 200 disturbances are noted annually, and the registers are published separately or collectively by the K. Akademie der Wissenschaften in Wien.

At Trieste, Laibach, Kremsmunster, Lemberg, and Pribram there are instruments to record earthquakes with a distant origin. Four of these stations have received State subventions. The registers are published in series with the above.

An important publication issued by Dr. A. Belar, of Laibach, is 'Die Erdbebenwarte.' In it we find articles relating to seismological investigations, notes relating to such work in general, and a catalogue of the Laibach observations.

2. *Belgium.*

Station Géophysique d'Uccle. Registers relating to earthquakes with distant origins are published every three months.

3. *Germany.*

Strassburg issues a monthly register of earthquakes with distant origins with corresponding notes from a few foreign stations, together with a list of a few earthquakes which have been felt in various parts of the world. It is supported by the State.

Hamburg issues a list similar to that issued by Strassburg, but more complete. The station was started as a private enterprise by Dr. R. Schütt, but its founder has presented the same to the city authorities.

Gottingen issues a register relating to the observations made at the University.

Teleseismic observations are also made at Jena and Potsdam. It is proposed to establish thirty-four more stations within the German Empire.

4. *Great Britain.*

A Committee of the British Association enjoys the co-operation of thirty-nine stations, which are fairly evenly distributed over the world. Each station is provided with similar apparatus intended for a particular class of teleseismic observation. The registers from these stations are published every six months, to which is added once a year a short report. These publications are distributed to the co-operating stations and to those who desire them. Support is obtained from the British Association, from the Royal Society, and private sources.

5. *Greece.*

D. Eginitis has published a catalogue of local disturbances, 1893–1898.

6. *Holland.*

The Magnetic and Meteorological Department in Batavia observes and publishes records relating to earthquakes of local and distant origin. Supported by the State.

7. *Hungary.*

Earthquakes are observed by a system similar to that adopted by Austria. At Buda Pest, Agram, O'Gylla, Fiume, and at a few other stations, instruments have been installed to record earthquakes with a distant origin.

8. *Italy.*

In Italy there are about 800 stations at which earthquakes are observed. Out of these there are fifteen first-class observatories provided with apparatus to record teleseisms and local shocks, and 150 second-class stations using seismoscopes. Since 1879 these have been under State control. The registers are published by the Central Meteorological Office in Rome, and to these are added corresponding records from nearly all the teleseismic stations of the world. This catalogue therefore practically contains the information relating to teleseisms contained in registers issued by all other nations. A few observatories, as, for example, those at Padua and Florence, also publish their records separately.

9. *Japan.*

Japan has at least five stations for teleseismic observations, and about eighty provided with instruments for recording local shocks. Records of these latter are made at over 1,000 centres, and as from 1,000 to 2,000 earthquakes are recorded annually, and as each of these may be noted at many centres, the number of manuscripts accumulating at the Central Observatory in Tokyo is very great. Accounts of the more important shocks are published in the 'Official Gazette' and in other newspapers.

A catalogue of 8,331 shocks (1885–1892) was published in the 'Seismological Journal,' and a similar but more extensive catalogue is now in progress.

The Earthquake Investigation Committee issue many publications relating to seismology, while papers on the same appear in the Tokyo Physico-Mathematical Society. Very many of the publications are in Chinese characters. At the University there is a Professor and an Assistant Professor of Seismology.

Practically all work is supported by the Government, the Investigation Committee alone receiving 1,000*l.* to 5,000*l.* a year.

10. *Norway.*

In connection with the Museum in Bergen Dr. Kolderup is issuing an annual list of earthquakes felt in Norway.

11. *Roumania.*

The 'Institut Météorologique de Roumanie' issues occasional sheets relating to teleseisms.

12. *Russia.*

In Russia and Siberia there are seven stations of the first order at which teleseismic and other shocks are recorded, and ten or twelve stations of the second order. Teleseismic records and special papers are published by the 'Commission Centrale Sismique Permanente.' Some of the stations, like Tiflis, Taschkent, and Irkutsk, also publish their records separately.

13. *Servia.*

Servia has a station in Belgrade.

14. *Switzerland.*

In 1880 F. A. Forrel and Heim arranged an organisation to collect records relating to shocks originating in Switzerland. These are published by the Meteorological Bureau.

15. *United States of North America.*

The Department of the Interior, in the monthly bulletin of the Philippine Weather Bureau, publish a list of teleseisms recorded in Manila, and a list of earthquakes recorded in the Philippines.

In California there are about twenty stations furnished with apparatus to record local disturbances. Lists are published in the Bulletin of the U.S. Geological Survey.

VII. *Directions in which Seismological Work may be extended.*

From the preceding section it may be inferred that at the present time there are about eighty stations at which teleseismic disturbances are recorded, and that nearly half of these are in Central Europe.

To obtain a fairly even distribution of stations over the surface of the world about twenty-three more places of observation are required. A possible distribution for these is as follows :—

Alaska, 1 ; U.S.A., Central Canada, Newfoundland, and Central America, 7 ; South America, 3 ; Iceland, 1 ; N. Norway, 1 ; Africa and Aden, 3 ; China, 2 ; the East Indies and the South Pacific, 5.

A more immediate requirement is, however, the establishment in and near to districts from which world-shaking earthquakes originate of sets of ordinary seismographs, together with the co-operation of observers provided with good time-keepers, or even fairly good watches. In districts remote from telegraphs or observatories these may be rated by sun observations. A simple method of making such an observation sometimes employed at Shide and Cassamiccola is as follows. In a brick wall facing south a hole has been made which on the outside is covered by two pieces of sheet iron brought together to leave a vertical slit about 5 mm ($\frac{1}{4}$ in.) in width and 40 cm. (16 in.) in height. The sun passing before this slit throws an image of the same upon the opposite wall 14 feet distant. On this wall opposite the slit and in a north-south plane with the same there is a vertical line. When the image reaches this, the sun is due south at an observed time. To the time when this occurs the equation of time is added or subtracted and local mean noon is obtained within about one second.

The object of these time observations, which may be made quite well with an ordinary watch, is to obtain the time of arrival of earth movement at various points round an epicentre, from which may be calculated the positions of foci of world-shaking earthquakes, not alone from the initial disturbance, but also from 'after shocks,' which latter seldom reach distant places.

When we know these *foci*, local observations enable us to make close approximation to the times at which large earthquakes have originated; and when this is done our knowledge of the rates at which motion has been propagated in various directions through and round the world will become more reliable.

The districts where such observations are required are indicated on the map, Plate II.

District E (Japan) is already well supplied with seismographs. Districts requiring similar installations are: A (Alaska), B and C (Central America and the West Indies), and K (Caucasian Himalayan district). In each of these at least six seismographs and the means of obtaining good time are needed.

Other lines upon which geophysical and seismological research might be conducted, but which have hitherto received but small attention, are numerous. Our knowledge of earthquake movement as recorded underground as compared with that noted upon the surface requires extension. As far as we can learn from the excellent work inaugurated in the Adalbert Shaft at Pribram by Dr. Edmund V. Mojsisovics, it would appear that the movement, at a depth of 1,115 m., is for world-shaking disturbances practically identical with that noted on the surface, from which it may be inferred that for this class of earthquake the large waves are not a mere superficial disturbance of the earth's crust.

Whether suboceanic disturbances are accompanied by molar displacements and large changes in suboceanic configuration remains to be determined by soundings the results of which should be of value to the hydrographer.

The fact that at certain observatories unfelt teleseismic movements are accompanied by perturbations of magnetic needles, which disturbances remain without satisfactory explanation, suggests that if such irregular perturbations are due to the influence of local subjacent magnetic magmas, in such localities not only should magnetic intensity be abnormal, but also that the differences between the observed and calculated values for gravity should be unusual.

What are the relationships between seismic and volcanic activities? and, further, what are the relationships between such phenomena, changes of level, magnetic elements, and the value for gravity? are also questions the answers to which are at present largely based upon hypotheses.

The movements on fault lines which accompany earthquake disturbances require an extended investigation, while the relationship which appears to exist between the dip and strike of rock folds and earthquake movement is a subject that has received but little attention.

Much has already been done to establish a relationship between earthquake frequency and certain astronomical phenomena; but fields for investigation, as, for example, the connection between movements of the earth's crust and the wanderings of the pole, have yet to be exploited. Again, as bearing upon earthquake occurrence, secular movements of the earth's crust, as, for example, those which are evidenced by changes in water level, alterations in the lengths of base lines and levels, the increase or decrease in the water-holding capacity of certain basins, have yet to be subjected to extended and careful measurements.

The harmonisation of results obtained from seismometry relating to the probable nature of the interior of the world with the requirements of astronomy, geodesy, the revelations of the plumb-line and the thermometer, together with various branches of physical, chemical, and geological research, constitute inquiries of profound interest.

Surface warpings of the earth's crust due to lunar or tidal influence or the variations in load which accompany changes in meteorological conditions may not only have a bearing upon earthquake frequency, but also may throw light upon the variations in flow and the rise and fall of subterranean waters, the escape of gases, and even perhaps assist the meteorologist in his forecasts of the weather.

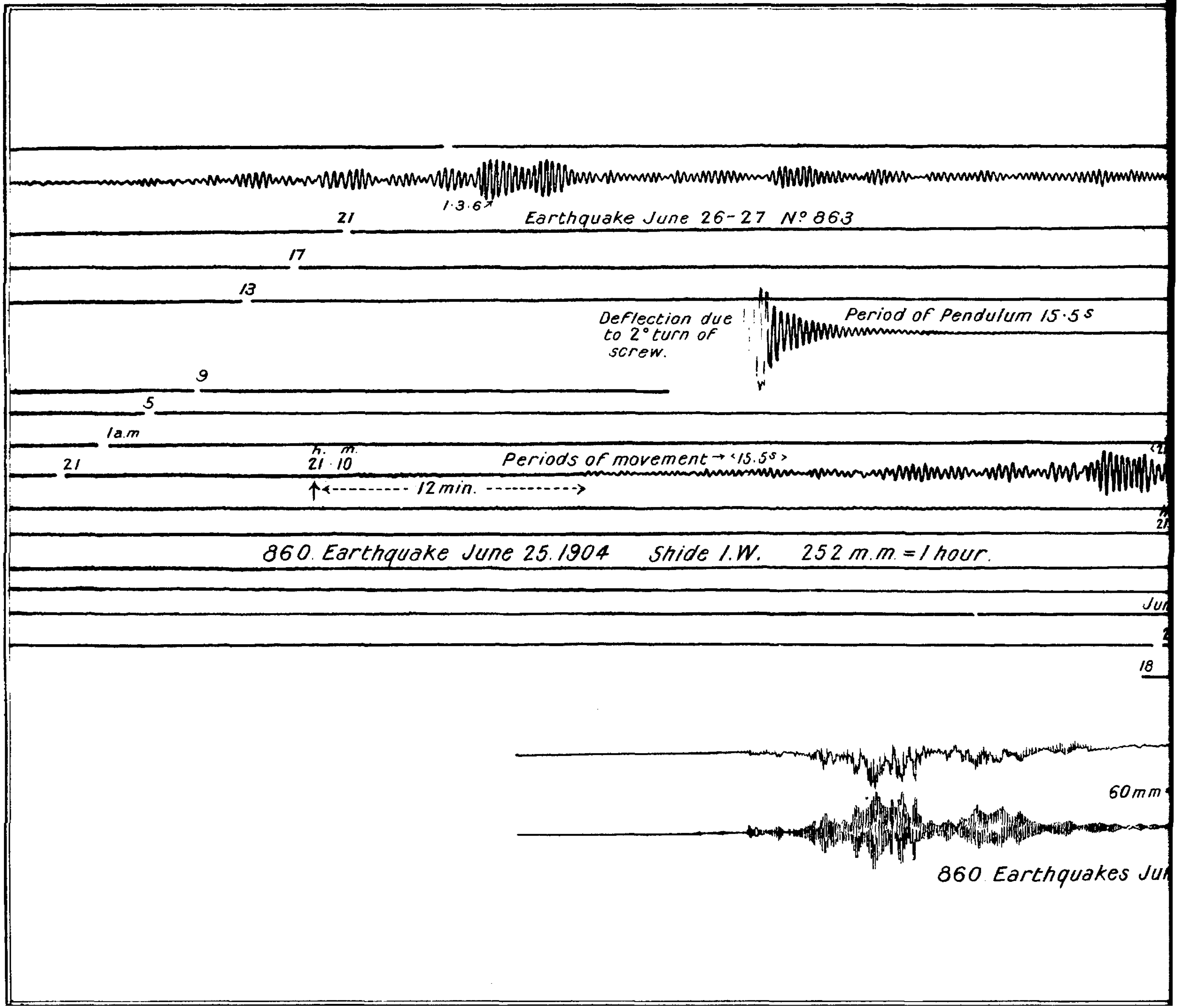
As illustrative of the practical outcome of seismological investigation the following may be mentioned :—

From observations on the destructive effects of earthquakes, the knowledge obtained respecting the actual nature of earthquake motion, and from experiments made upon brick and other structures, new rules and formulæ for the use of engineers and builders have been established. In Japan and other countries these have been extensively applied in the construction of piers for bridges, tall chimneys, walls, ordinary dwellings, embankments, reservoirs, &c. Inasmuch as the new types of structures have withstood violent earth-shakings, whilst ordinary types in the neighbourhood have failed, it may be inferred that much has already been accomplished to minimise the loss of life and property. These investigations have yet to be extended.

The application of seismometry to the working of railways, particularly in Japan, has led to the localisation of faults on lines and alterations in the balancing of locomotives. The result of the latter has been to decrease the consumption of fuel.

Records of the unfelt movements of earthquakes indicate the time, the position, and, what is of more importance, also the cause of certain cable interruptions. The practical importance of this latter information, especially to communities who may by cable failures be suddenly isolated from the rest of the world, is evident. The many occasions that earthquake records have furnished definite information respecting disasters which have taken place in distant countries, correcting and extending telegraphic reports relating to the same, is another indication of the practical utility of seismic observations. Seismograms have frequently apprised us of sea waves and violent earthquakes in districts from which it is impossible to receive telegrams, whilst the absence of such records has frequently indicated that information in newspapers has been without foundation, or at least exaggerated. The localisation of the origins of world-shaking earthquakes, besides indicating suboceanic sites of geological activity, have indicated positions where the hydrographer may expect to find unusual depths. They have also shown routes to be avoided by those who lay cables.

In addition to the above, a great proportion of which relates to what may be called the field work of seismology, there are many subjects bearing upon the same science which remain to be investigated within the walls of a laboratory ; and as it seldom happens that any one research fails to suggest new departures, the work of to-day implies new and extended investigations in the future.


1.3.6
21
Earthquake June 26-27 No. 863
17
13
Deflection due to 2° turn of screw.
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5
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h. m.
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Periods of movement → ‹15.5s›
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860. Earthquake June 25. 1904 Shide I.W. 252 m.m. = 1 hour.
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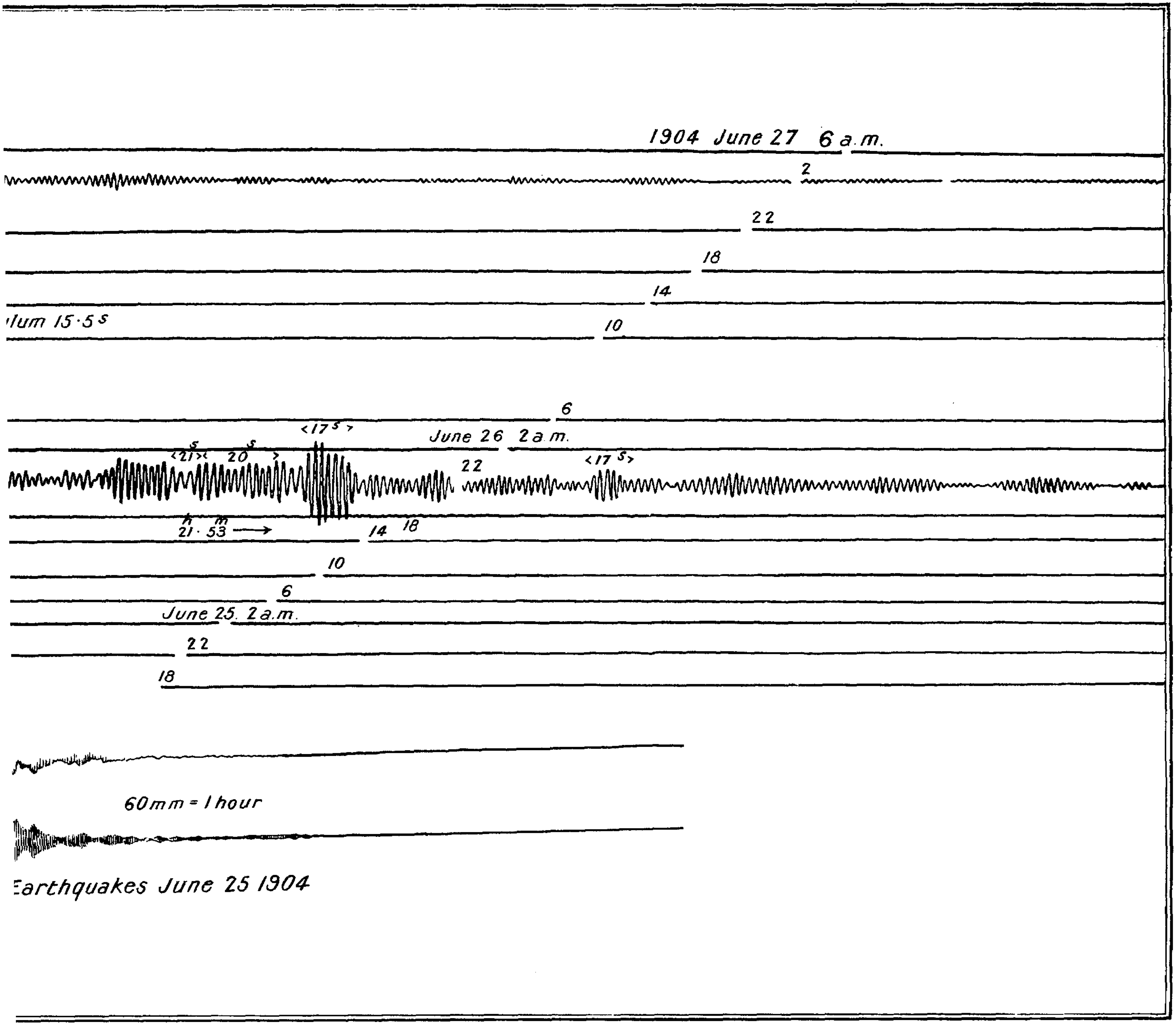
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2
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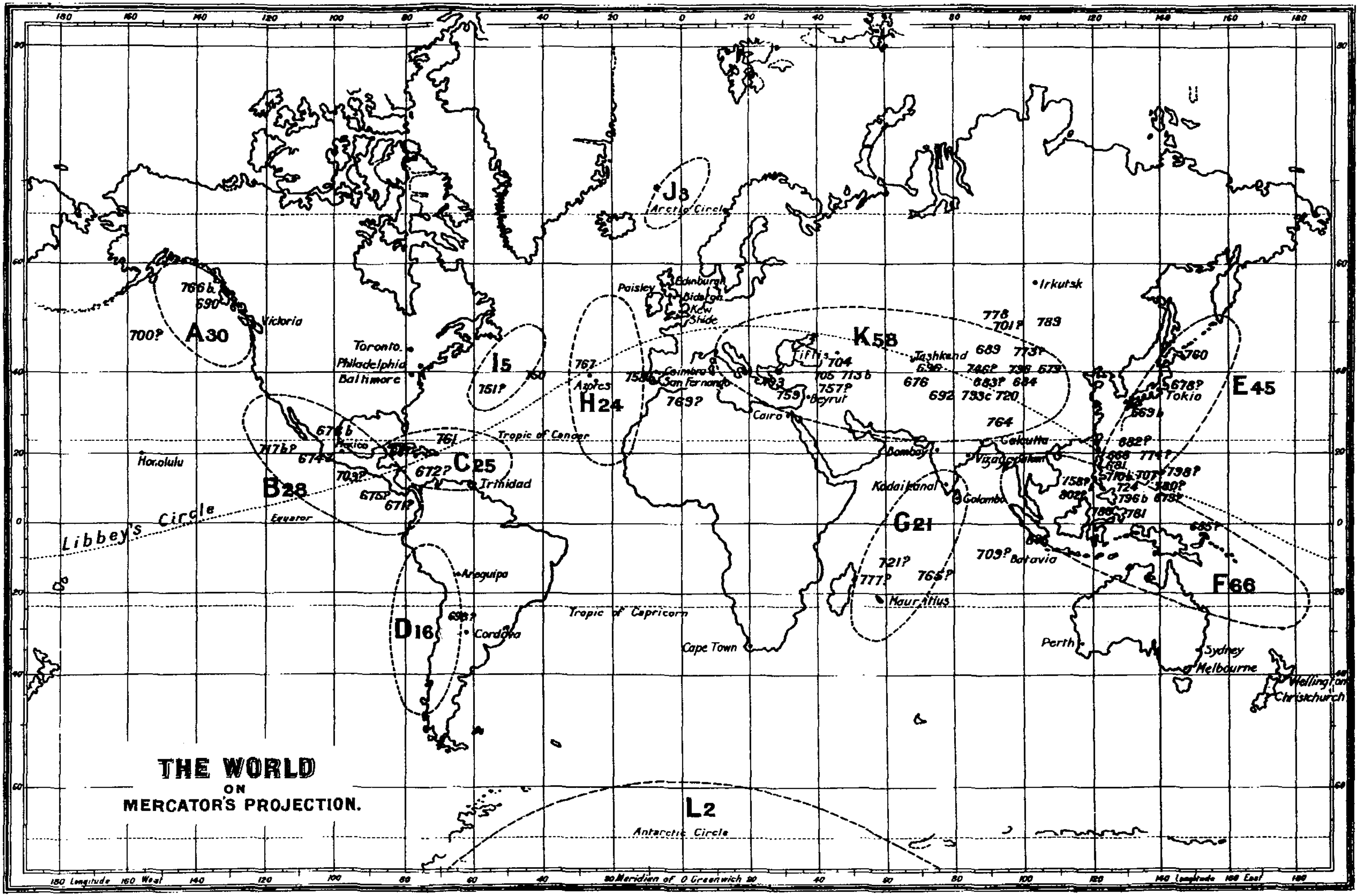
60mm = 1 hour
Earthquakes June 25 1904

Origins for 1903 are indicated by their B.A. Shide Register number. Earthquake districts are indicated A, B, C, &c., and the number of earthquakes which since 1899 have originated from these is expressed in large numerals. Observing stations are named.



Illustrating the Report on Seismological Investigation.

VIII. *The Experiment at the Ridgeway Fault.*

Mr. Horace Darwin informs the Committee that he visited Upway in March last, when he took out most of the apparatus and put new in its place. This seems to be working well, and if it continues to do so he hopes to furnish a detailed report on the relative movements of the two sides of the fault next year.