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REPORTS ON THE STATE OF SCIENCE, ETC.

Seismological Investigations.—Twenty-fifth Report of the Committee, consisting of Professor H. H. TURNER (*Chairman*), Mr. J. J. SHAW (*Secretary*), Mr. C. VERNON BOYS, Dr. J. E. CROMBIE, Sir HORACE DARWIN, Dr. C. DAVISON, Sir F. W. DYSON, Sir R. T. GLAZEBROOK, Professors C. G. KNOTT *and* H. LAMB, Sir J. LARMOR, Professors A. E. H. LOVE, H. M. MACDONALD, J. PERRY, *and* H. C. PLUMMER, Mr. W. E. PLUMMER, Professor R. A. SAMPSON, Sir A. SCHUSTER, Sir NAPIER SHAW, Dr. G. T. WALKER, *and* Mr. G. W. WALKER.

General.

THE transference of the Milne books and apparatus from Shide to the University Observatory at Oxford was completed in September last. Mrs. Milne sailed for Japan, after some shipping delays, on September 27, and news of her safe arrival on November 13 has been received. The greater part of the books, records, cards, and the two globes for preliminary calculations are conveniently housed in a room in the Students' Observatory, apart from the main building: the remainder of the material is for the present stored in an outbuilding. But by a timely benefaction of 400*l.* from Dr. Crombie, a small house has been acquired near the Observatory, of which it is hoped to get occupation in September, and this will easily hold all that is required, and serve at the same time as a dwelling for the seismological assistant. These arrangements have been made in accordance with the spirit of Professor Schuster's resolution (quoted in the last report), offering to establish a Central Bureau at Oxford, which could not be exactly carried into effect at the moment owing to circumstances there mentioned. Further, in pursuance of this plan, the Cambridge Committee entrusted with the appeal for a Geophysical Institute which should include Seismology, finding their appeal unsuccessful, passed the following resolution on March 10, 1920:—

> It was agreed that Professor Turner should be informed that no objection could be taken by the Committee to a seismological station and establishment at Oxford.

This resolution, with a letter from the Chairman of the Committee and a summary of other information, was next reported to the University of Oxford through the Board of Visitors in May last, and approved. Finally, these facts were reported to this Committee (B.A. Seismology) at its meeting on July 2, and the plan of locating the work at Oxford approved. It remains to obtain the funds necessary for the salary of a full-time director and for replacing the grants temporarily made by the British Association and the Royal Society. A Royal Commission is at present reviewing the finances of the Universities of Oxford and Cambridge, and a note has been addressed to this Commission on the subject of Seismology, in the first instance by the Board of Faculty of Natural Science, supplemented by a more particular note from Professor Turner.

Instrumental.

The Milne-Shaw seismograph erected in the basement of the Clarendon Laboratory has worked well through the year. Professor Lindemann has given formal sanction to the arrangement, and included the basement in his general installation of electric light in the laboratory. This has much facilitated the operations of changing films, comparing clocks, &c., but the gas-jet is retained for the photography. The room has further been cleaned and whitewashed, and an outer door has been added shutting it off from draughts. It is now a very convenient laboratory, and is large enough for the erection of at least one more machine, when one is available.

The Milne-Shaw machine formerly erected at Eskdalemuir for direct comparison with Galitzin records has been now transferred (on loan) to the Royal Observatory, Edinburgh, and readings have been received from July 4, 1919. The situation seems peculiarly liable to microseismic disturbance, obviously connected with wind.

The instrument mounted in the 'dug-out' near West Bromwich has given some interesting results as regards these microseisms on which Mr. Shaw writes a special note at the end of this report.

Various other instruments are being constructed as rapidly as present difficulties permit.

Milne-Shaw machines have recently been dispatched to Cape Town, Montreal, Honolulu, and Aberdeen. Others are being made for India, China, Egypt, New Zealand, Canada, and Ireland.

Bulletins and Tables.

'The Large Earthquakes of 1916' have been collated and published as a single pamphlet of 116 pages, but there are great difficulties in obtaining satisfactory determinations of epicentres for the later war years, which have delayed further publication.

The corrections to adopted tables have not yet been completed.

Earthquake Periodicity.

The study of long periods in the 'Chinese Earthquakes' directed attention to a period near 260 years. This was in the first instance identified as 240 years ('Mon. Not. R.A.S.,' lxxix., p. 531) as mentioned in the last report, and Mr. De Lury pointed out that this value also suited tree-records (Pub. Amer. Ast. Soc. 1919). But an investigation on the secular acceleration of the Moon by Dr. Fotheringham recalled attention to a value nearer 260 years, which was also found to suit the tree-records ('Mon. Not. R.A.S.,' lxxx., p. 578) over the same period. Ultimately a much longer series of tree-records was obtained (Mr. A. E Douglass's compilation from 1180 B.C.) and a full analysis of these, now in the press ('Mon. Not. R.A.S.,' 1920 Supp. No.), suggests a double periodicity, with components of approximate lengths 284 and 303 years. Long as it is, the series of tree-records is not long enough to separate these components themselves : the evidence for separation is provided by the harmonics, especially the third harmonic, which shows components of 101 years and 94·4 years clearly separated, the former and longer being the stronger, whereas in the main terms the shorter period is the stronger. The second harmonic of the longer period, *i.e.*, half 303, or, say, 152 years, is quite possibly the 156-year period referred to in the last report.

These results have been obtained so recently that their full relation to the earthquake records have not yet been worked out. But a welcome confirmation may be mentioned. In the 'Bull. Seism. Soc. of America,' vol ii., No. 1, Miss Bellamy found a later list of 'Chinese Earthquakes' compiled by N. F. Drake. It is not entirely independent of the catalogue already studied (compiled by Shinobu Hirota in 1908 and mentioned by Drake as having been received too late for inclusion or comparison), but it differs from it in one important respect, being copious in the later centuries where Hirota's catalogue is scanty. Further, it is confined to 'destructive or nearly destructive' earthquakes, so that the records are probably more precisely comparable *inter se*, although they still show a large increase about A.D. 1300, which must be attributed to greater completeness of the later records, or rather imperfection in the earlier years. The following table gives the analysis in periods of 284 years :—

TABLE I.

Numbers of Chinese Destructive Earthquakes (Drake).

Initial Year	2081 B.C. to 94 B.C.	93 B.C. to A.D. 190	191 to 474	475 to 758	759 to 1042	1043 to 1326	1327 to 1610	1611 to 1894	Total	Revised
0	1	2	1	2	2	3	28	27	66	48
24	2	2	1	5	2	7	21	12	52	58
48	0	3	2	0	3	2	1	11	22	25
71	1	2	4	0	2	5	0	2	16	28
95	0	0	5	1	3	0	7	8	24	27
119	0	2	10	1	2	1	9	5	30	39
142	2	0	0	3	0	4	26	7	42	37
166	3	3	4	1	1	7	30	4	53	53
190	4	5	0	0	1	0	23	9	42	42
213	0	7	2	0	2	4	22	12	49	39
237	1	7	1	1	9	9	23	15	66	68
261	0	3	1	4	3	18	22	14	65	63
Total	14	36	31	18	30	60	212	126	527	527

The totals in the last column but one are governed chiefly by the later cycles. To minimise this effect the eight columns were all reduced to the same total 66, using one place of decimals until the sums were formed. The results are given under the heading 'Revised,' and it will be seen that they give substantially the same curve, with pronounced minimum extending from the 48th year to the 118th, and a pronounced maximum at the end. The 48th year of the present cycle will be 1942, so that we are approaching the time of minimum quakes and have passed the maximum. But it is not yet clear whether these figures for China apply unmodified to the whole earth. It may be possible to observe this decline in the near future, but up to the present the records are affected by so many uncertainties, owing partly to the novelty of the science, partly to the war, and to other causes, that it is very difficult to compare one year with another. Thus the Eskdalemuir records show the following *total* numbers of earthquakes :—

1911	1912	1913	1914	1915	1916	1917	1918
236	393	287	278	184	163	166	192

which at first sight might be interpreted as a notable falling-off in earthquake activity, but is probably chiefly due to a change of method in 1915. The point will, however, be further examined. Analysing the last two columns of Table I. harmonically we get from the simple totals

$$20 \cos(\theta - 301^\circ) + 11 \cos(2\theta - 348^\circ) + 1 \cos(3\theta - 304^\circ) + 5 \cos(4\theta - 98^\circ)$$

from the revised

$$14 \cos(\theta - 304^\circ) + 8 \cos(2\theta - 340^\circ) + 3 \cos(3\theta - 211^\circ) + 8 \cos(4\theta - 138^\circ).$$

The third harmonic is small—smaller than the fourth, for instance. But on analysing the results in 101 years a larger term is obtained. The totals are (for twelve groups to the cycle, which gives nearly the same mean as above)

48 41 45 41 31 53 38 37 33 56 43 54

which gives a term $5 \cos(\theta - 331^\circ)$.

This is in accordance with the results found from trees—that the 101-year term should exceed the 94 year.

Microseisms. By J. J. Shaw.

Microseisms appear to have been a much neglected study. A few observers have counted them, measured their frequency and amplitude, and noted their seasonal character, but beyond this little seems to have been done. This is all the more remarkable in view of the fact that microseisms, unlike earthquakes, are always more or less available for investigation.

In 1911 the International Seismological Congress in Manchester allotted 500*l.* for their investigation, and as a result the Central Bureau at Strasbourg tabulated a number of observations, and, but for the European War, would probably have reported at Petrograd in 1914. If any conclusions were arrived at they do not appear to have been published.

In the 1917 report of this Committee attention was drawn to the readiness with which a microseismic wave could be identified at two adjacent stations (in that case, in separate buildings 60 feet apart).

The two machines, arranged with precisely similar constants, produced identical records of the microseisms; but an interesting feature was observed, that, when keeping the nominal magnifications of the two machines the same, and at the same time varying the relative sensitivity to tilt of one machine to as much as four times the other, the amplitude shown on the film remained the same on each machine. This seems to indicate that a microseismic wave is purely horizontal and compressional rather than of an undulating gravitational character.

In the same report it was suggested that, by gradually increasing the distance between the recording stations (but only so long as it was possible to identify the individual waves), it might be possible to trace the origin and cause of these movements.

With this object in view two suitable stations were secured. The one was the writer's household cellar at West Bromwich, the other a 'dug-out' in a pit bank at Millpool Colliery situated two miles away, and kindly placed at our disposal by T. Davis, Esq., of the Patent Shaft and Axletree Co., of Wednesbury.

The dug-out was a tunnel 60 feet into the mound and 15 feet below the surface. It lay 17° west of north of the 'home' station.

The first observations were made in March and April 1919, when for a few weeks two Milne-Shaw machines were available.

It was at once seen that at stations two miles apart the records of the microseismic waves were almost identical.

The clock in use at the dug-out was not of a sufficiently high standard to obtain the precise difference in time of arrival at the respective stations.

Several seismograms were obtained during this time and were seen to be similar in every detail.

In March and April of the present year a first-class timing clock was substituted, and two more machines installed with the intention of timing the microseismic wave over this two-mile base line.

The usual means of synchronising were not available, therefore the clocks were adjusted as follows :—

A watch with an excellent hourly rate was chosen and carried per motor-cycle between the stations. Two observations, with 30-minute intervals, were made on the home clock, two on the dug-out clock, and two more on the home clock. It was estimated that on favourable occasions the two clocks were set alike within one-tenth of a second. The clocks were checked once per day, and the waves timed by measuring on the film from a minute eclipse to the nearest apex at the extreme of an excursion.

This first method was continued from January 31 to February 15. As differences of 1½ to 2 seconds were shown—being probably erroneous—an effort was made during March to secure a closer comparison.

Firstly, the clocks were checked twice per day. Secondly, as, on a closer scrutiny, small fluctuations in the peripheral speed of the recording drums could be detected, it was seen to be inadvisable to measure any intermediate point during a minute, but to rely only upon the moment when the eclipsing shutter opened or closed.

The duration of the eclipse was 4·7 seconds in each case, so that opening or closing were equally serviceable as datum points. Therefore a new method of comparing the films was devised as follows :—

The eclipsing shutter was provided with a narrow slit through which a small percentage of light could pass when the shutter was closed. This feeble beam produced a ghost-like trace during the interval of each eclipse.

In making comparisons instances were chosen where the amplitude was not only large but also where the shutter had opened or closed near the middle or zero position of the wave.

The change of intensity of the trace was sharp and easily measured, whilst the extremity of the excursion could be seen in the ghost.

The period of the wave and its phase at the datum point having been determined, it was then possible to resolve the harmonic motion, and so obtain the difference in time to one-tenth of a second.

It is interesting to note that by either method the average difference was 0·8 second, but the second method gave much more consistent readings.

A further object was to note to what extent the direction of propagation, the amplitude, or the period were affected by meteorological conditions, particularly the direction and force of the wind.

We were indebted to A. J. Kelly, Esq., Director of the Birmingham and Midland Institute Observatory (four miles distant), for his help in this matter.

The force of the wind and the amplitude did appear to be co-related, inasmuch that the microseisms were small during calm spells and *vice versa*, but there was a notable exception on March 10. During March 9 and 10 the air movement had been small, 178 and 272 miles in each 24 hours respectively, yet on the evening of the 10th nearly the largest waves of the series were recorded.

Within a period of 24 hours, March 12 to 13, the velocity of the wind ranged from 37 to 12 and back to 37 miles per hour in three nearly equal periods, but there was no corresponding fluctuation in the amplitude of the microseisms. Similar fluctuations on other dates were equally ineffective to produce sudden change in the ground movement.

There was little variation in period. It was usually 6 to 7 seconds. On a few occasions it fell to 4·5 seconds, but never exceeded 8 seconds. It will be observed that the period appears to increase with the amplitude.

The outstanding, and we venture to think important, discovery was that the microseismic waves always arrived from the same direction. On every film they were seen to arrive at the 'dug-out' or northerly station first.

During the period of observation the wind blew from all points, except north to east, but no quarter seemed to affect the regularity with which the waves arrived from the north.

Column two in the following table gives the time in seconds by which the waves arrived at the dug-out first :—

By First Method.

Date	Difference, Sec.	Wind Direction	Daily Horl. Motion of the Wind, Miles	Amplitude μ	Wave Period, Sec.
1920					
Jan. 31	0·0	S—WSW	427	5·8	7·3
Feb. 2	0·0	SW—S	587	4·0	7·5
„ 6	1·5	SSE	295	2·8	6·7
„ 9	1·0	WSW	491	3·2	6·3
„ 10	1·0	SW	670	9·5	8·0
„ 12	0·0	WNW—S	354	3·6	6·2
„ 13	2·0	SSW—W	528	6·4	6·8
„ 15	1·5	S	423	5·0	6·2
Average	·87		472	5·0	6·9

By Second Method.

Date	Difference, Sec.	Wind Direction	Daily Horl. Motion of the Wind, Miles	Amplitude μ	Wave Period, Sec.
1920					
March 4	1·0	WSW—S	260	4·9	7·5
„ 5	1·0	S	285	1·6	6·7
„ 6	0·75	S	476	4·5	6·0
„ 8	1·1	NW	407	2·4	6·7
„ 9	—	W	178	—	—
„ 10	0·7	SSW	272	7·0	7·0
„ 11	1·1	NW	257	4·9	6·5
„ 12	0·5	W	541	5·7	6·0
„ 13	1·0	S	377	4·5	6·2
„ 18	0·8	W	500	4·0	6·7
„ 19	—	W	228	2·0	6·0
„ 20	—	W	131	0·8	5·5
„ 24	0·8	S	348	4·0	7·3
„ 26	0·7	S	613	5·3	7·3
„ 28	0·8	S	498	3·2	5·7
Average	·83		371	3·9	6·5

It will be observed that the time in column two is generally about one second, which is the approximate time required for a surface wave to travel two miles, thus indicating that the direction of propagation was more or less constant and approximately from north to south.

On the other hand there are differences ranging between 0·7 sec. and 1·1 sec. Remembering the method of synchronising the clocks it is possible many of the irregularities are due to personal and instrumental error. To what extent they indicate that the azimuth wanders round the northern semicircle it is difficult to determine, but from the fact that the southern half was never indicated, it would seem feasible to presume that the waves came generally from the north.

More precise information is very desirable, and can only be obtained from not less than three stations with preferably a longer base of operation, and with better timing facilities.

It is hoped, at some future date, when three machines are simultaneously available and suitable quarters and observers found, to make the experiment on a ten-mile triangle.

An attempt was made to identify the microseisms recorded at Oxford with those of West Bromwich (80 miles apart), but unfortunately the booms are oriented 90° from each other. From some measures made by Professor Turner there was a suggestion of agreement, but nothing really tangible has at present been detected.

A fruitful investigation for observatories would be to determine whether this unidirectional character of microseisms is general, and whether the azimuth depends upon the contour or physical features of a country.

From the foregoing it is clear that microseisms are real travelling waves of the same character as those propagated by earthquake shocks, and if a seismograph fails to perceive them then it is not recording all that is passing.

Two stations where Milne-Shaw instruments are installed, viz., Bidston and Edinburgh, seem to be very liable to microseisms. Both stations are near the sea, and both stand upon the crest of a hill.

Shide was within six miles of the open sea, but did not stand upon a hill. This station did not find the microseisms more prevalent than an average station.

Oxford and West Bromwich are well removed from the sea. They record microseisms as freely as Shide. It has yet to be determined whether the sea-board is more liable to these movements : the evidence points to that conclusion.

The P phase of a seismogram sometimes, but not often, begins with a sharp kick—denoted *i P; but sensitive machines show that much more* frequently this sharp kick is preceded by two or three waves of smaller amplitude and higher frequency. When the frequency is distinctly quicker than that of the prevailing microseisms, and the amplitude of the latter is not too great, it is easy to detect the true P as a superimposed wave, but if the period of these small precursors approximate to that of the microseisms, then it is difficult to determine the true inception of the earthquake record.

Machines which do not record the microseisms will not record these minute waves. With such machines probably more uniformity, by reading the bigger kick, will result, but misguided uniformity will not be conducive to obtaining the true rate of propagation of the P phase.

It is to sensitive machines and careful scrutiny of the record that we must look for data for the perfecting of seismological tables.