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A WORLD-WIDE SURVEY OF MICROSEISMIC DISTURBANCES

Recorded during January, 1930

By A. W. LEE, M.Sc., A.R.C.S., D.I.C.

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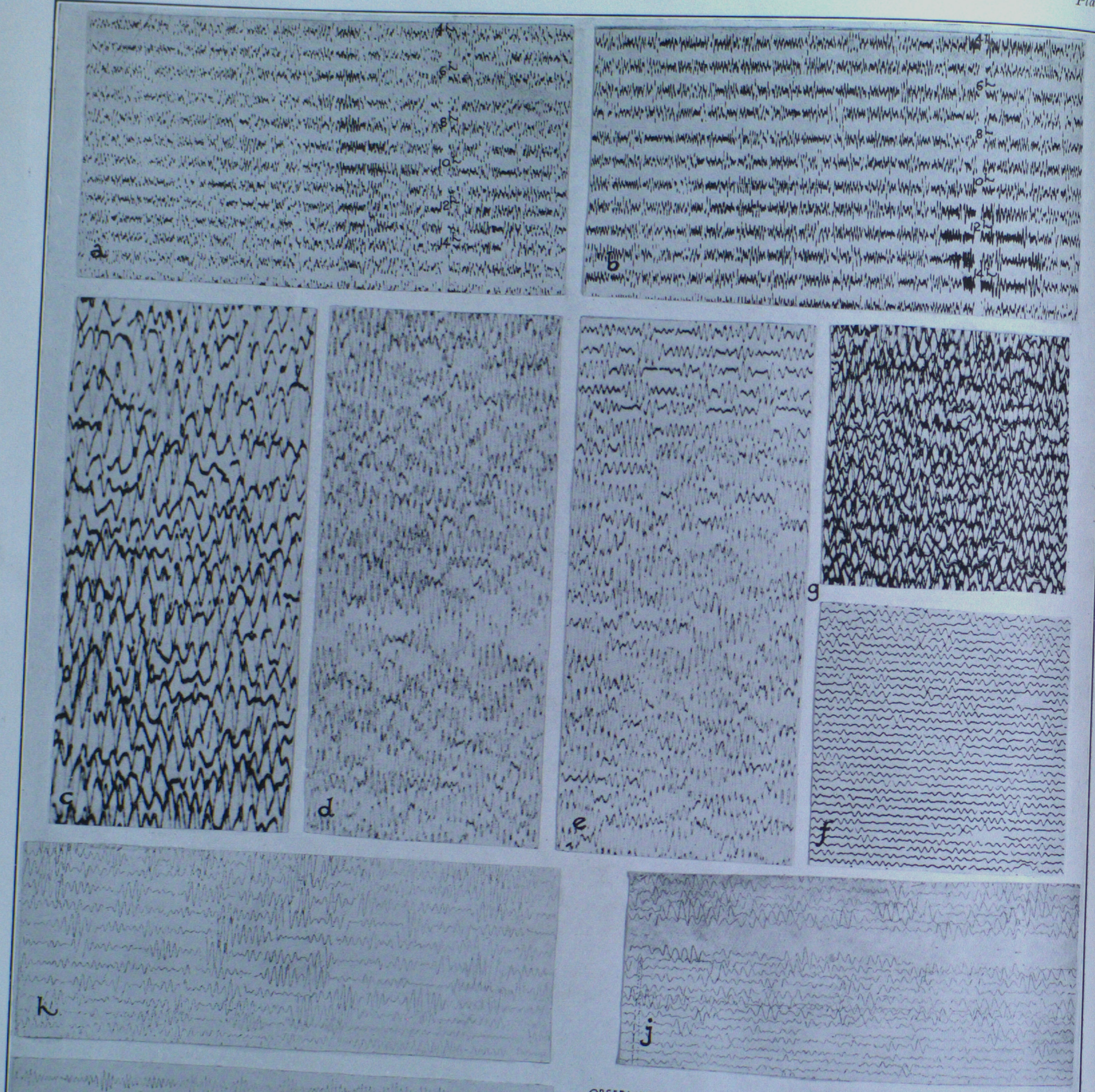

OBSERVATORY	TYPE OF SEISMOGRAPH	COMPONENT	JAN. 1930.
a. Honolulu	Milne-Shaw	N-S	16
b. "	"	E-W	16
c. Strasbourg	Galitzin	N-S	11-12
d. Scoresby Sund	"	E-W	20-21
e. "	"	N-S	31
f. Abisko	"	N-S	7-8
g. "	"	N-S	20-21
h. Ivigtut	Wiechert	E-W	1-2
i. "	"	Z	1-2
j. Reykjavik	Mainka	N-S	21-22

Fig. 1.—Typical records of microseisms

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A WORLD-WIDE SURVEY OF MICROSEISMIC DISTURBANCES

RECORDED DURING JANUARY, 1930

§ 1—INTRODUCTION

About fifty years have passed since, with the development of the seismograph for recording the ground movements caused by earthquakes, other disturbances were first observed. The nature and origin of these disturbances have been investigated in many researches. It has been found that the effects of traffic or machinery in the vicinity may be shown in the seismograms as a series of very rapid oscillations, the period of the waves being 1 or 2 seconds (1)* ; at some observatories rather irregular oscillations with periods greater than about 10 seconds can be attributed to local strong winds and possibly also to frost (2, 3). The most regular and most widely observed movements, however, are those with periods 3–10 seconds which are nearly always visible in the seismograms. They occur in the records of the vertical component as well as in those of the horizontal components, and are larger in winter than in summer. Many hypotheses have been brought forward to explain how these oscillations are caused but none has yet been generally accepted.

In the earlier literature of the subject the movements which were not caused by earthquakes were termed "earth tremors," "pulsations," or "pulsatory oscillations." More recently these designations have given place in English publications to "microseisms" or "microseismic disturbances." The term "microseism" is confusing for frequently it is used in connexion with small earthquakes ; in the present paper it is employed as an abbreviation for the more logical but rather cumbersome alternative, and its application is restricted to the regular oscillations of period 3 to 10 seconds. Unfortunately in English we have no word so appropriate as the German *Bodenunruhe*. Portions of seismograms, illustrating microseisms recorded at various observatories and by different types of seismograph, are reproduced in Fig. 1. (*Frontispiece.*)

The amplitude and period of the microseisms recorded at selected hours are published regularly by a number of observatories. Such tabulations are available for two observatories in Great Britain, a Galitzin installation having been in operation at Eskdalemuir Observatory and subsequently at Kew Observatory ; the tabulations of the N-S component microseisms are available for Eskdalemuir from 1911 to 1925 and for Kew since 1926 (4, 5). To obtain a more complete representation of the microseismic activity the records for one month (January, 1930) were collected from the seismological observatories of Great Britain and the

* The numbers in brackets refer to the bibliography on p. 28.

microseisms were tabulated for four hours daily ; this material has been discussed in two recent papers (6, 7). The investigations showed that the mean amplitude of the microseisms varies from place to place according to the geological structure in the vicinity, and that the fluctuations of amplitude and period in any part of Great Britain are related to those in other localities. The data would be consistent with a diminution in the disturbance from north to south, but the area covered is too small for the geographical distribution of the microseisms to be determined with certainty. Since the geographical distribution is of the utmost importance for examination of the theory that the microseisms are associated with atmospheric storms an extended investigation was required. It was also necessary to examine from the data of as many stations as possible, the theory that the microseismic amplitudes depend upon the geological formations.

It was therefore decided to organise a survey of microseisms throughout the world during January, 1930, and every observatory equipped with suitable instruments* was requested to collaborate in the investigation by supplying tabulations. The response has been very gratifying and has yielded information about the microseisms in many localities not hitherto investigated. The complete data include the old tabulations for seven British observatories, sets of tabulations prepared locally at 35 observatories, data for 15 observatories from which the the records were forwarded to Kew Observatory for measurement, and supplementary information from 10 observatories where full tabulations could not be made.

The most important of the results which have been achieved are :—

(a) The effect of the subsoil upon the amplitude of the microseisms has been put upon a rational basis.

(b) The determination of the principal regions subject to " microseismic storms."

(c) The geographical distributions of microseisms in Europe have been obtained for a number of cases. They closely resemble the associated distributions of atmospheric pressure, the microseisms being largest in the regions of lowest pressure.

(d) The demonstration that the microseisms in Europe are not always large when deep depressions are located over the eastern Atlantic.

§ 2.—TABULATION OF THE MICROSEISMS

Fig. 2 shows typical records of large microseisms obtained from the Galitzin seismographs at Kew Observatory. The oscillations in each component increase and diminish in a manner which suggests that more than one system of waves is affecting the seismograph ; the phase difference between the components may apparently have any value from 0 to 2π, and the maximum amplitudes of the components need not occur in the same group of waves. To overcome the difficulty of measuring the amplitudes when the oscillations vary in size, measurements are made from the largest group of well developed microseisms during an interval centred at the selected hour. The interval covered for the routine tabulations is generally 30 minutes, but for the measurements of this research the interval has been reduced to 10 minutes. The tabulations for January, 1930, indicate that for the N-S component at Strasbourg and at Kew the amplitudes for the former system of tabulation (30 minutes) are on the average about 20 per cent. greater than those for the other system ; the average difference between the two determinations of the E-W component amplitudes at Strasbourg amounts to about 10 per cent. Daily values of the amplitude and period at 18h. for the N-S component at Kew are shown

* The observatories were mostly selected from " List of Seismological Stations of the World." *Bulletin of the National Research Council, No.* 82. Washington (1931).

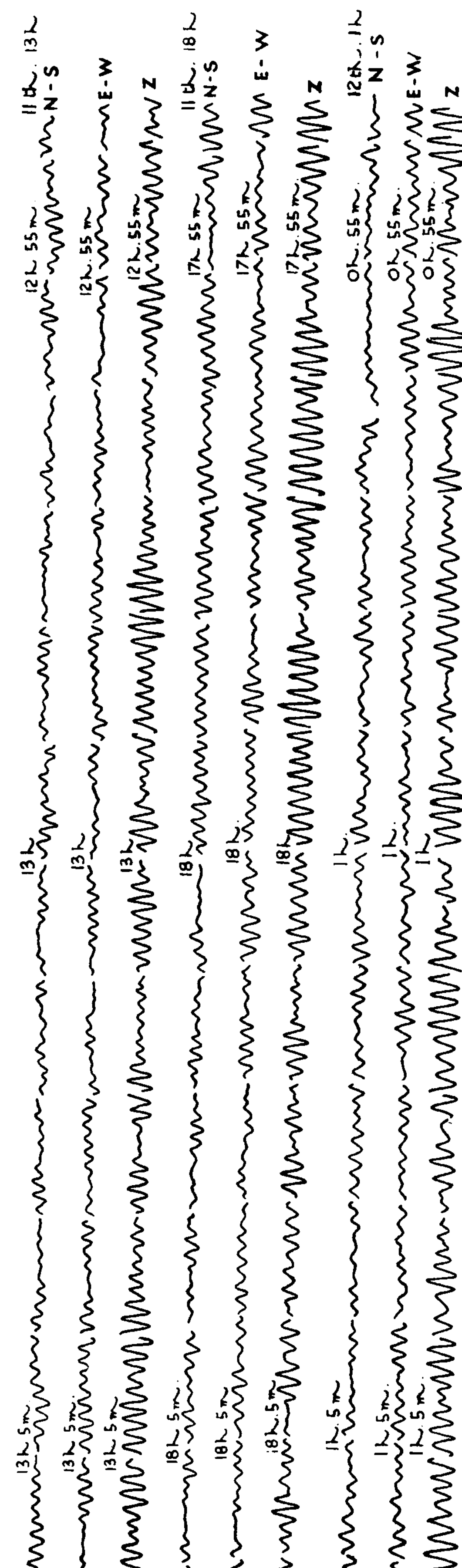

FIG. 2 LARGE MICROSEISMS RECORDED AT KEW OBSERVATORY, JANUARY 11-12, 1930.

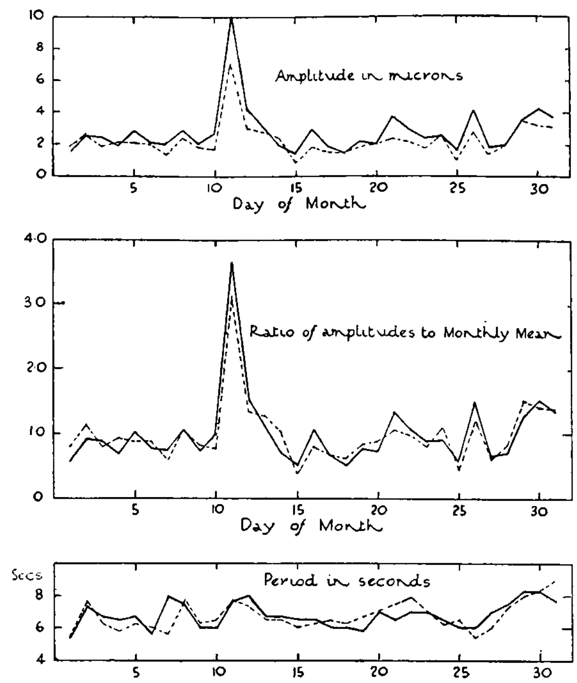

FIG. 3.—DAILY AMPLITUDES AND PERIODS OF MICROSEISMS OF N. COMPONENT AT 18H. RECORDED AT KEW OBSERVATORY, JANUARY, 1930.

VALUES FOR AN INTERVAL OF 30 MINUTES CENTRED AT THE HOUR ARE SHOWN BY FULL LINES, THOSE FOR AN INTERVAL OF 10 MINUTES BY DOTTED LINES.

in Fig. 3; the data for an interval of 30 minutes centred at the hour have been taken from the *Observatories' Year Book*. For the longer interval the mean amplitude is 2·76 μ and the mean period 6·79 sec., and for the shorter interval the means are 2·26 μ and 6·76 sec. The second pair of curves in the figure shows that the differences between the two methods of tabulation are less serious if the ratios of the amplitudes to the monthly means are taken rather than the actual ground movements.

Following the procedure adopted in studying the microseisms in Great Britain, observatories participating in the survey were requested to furnish tabulations of each available component for the hours of the International Synoptic Observations (1h., 7h., 13h. and 18h., G.M.T.). For the measurements the group of microseisms was selected which

(a) was within 5 minutes of the hour,

(b) lasted for about 30 seconds, and

(c) had a larger amplitude than other groups satisfying conditions (a) and (b). The mean period of the observations was measured (to the nearest 0·2 sec.) from the whole group, and the mean amplitude (to 0·1 mm.) from the three largest consecutive oscillations. The amplitudes as measured from the seismograms were converted into earth movements (to 0·1 μ) by using a factor appropriate to the period at that time. The formula used for computing the factors depends upon the type of the seismograph; with photographic registration the formulæ given by the designers of the various instruments were used. For seismographs which record mechanically the factors were obtained from E. Wiechert's formula :—

$$\text{magnification} = V\{(u^2-1)^2 + 4h^2u^2\}^{-\frac{1}{2}}$$

in which V is the " static magnification," $u = T/T_0$ or the ratio of period of the earth wave to the free period of the seismograph, and

$$h = [1 + (\pi/\log_e \nu)^2]^{-\frac{1}{2}}$$

where ν is the damping ratio.* The constants for each observatory accompanied the tabulations and the reductions were checked on receipt of the data to ensure uniformity in the methods.

The seismographs are of eight types, four with photographic registration, and four with mechanical registration. The use of the various kinds of seismograph for recording the different components is shown in the following table :—

* If the seismograph is set swinging the ratio of successive amplitudes as the oscillations subside is termed the damping ratio.

TABLE I—SEISMOGRAPHS PROVIDING TABULATIONS OF MICROSEISMS DURING JANUARY, 1930

Type of seismograph	Method of recording	Component		
		N–S	E–W	Z
G. Galitzin	photographic	11	9	10
M.S. Milne-Shaw ..	,,	11	11	—
W.A. Wood-Anderson ..	,,	3	1	—
B. Belar	,,	—	1	—
W. Wiechert*.. ..	mechanical	15	16	6
M. Mainka	,,	5	3	—
Q.P. Quervain-Piccard†	,,	2	3	—
Bf. Bifilar (La Paz) ..	,,	—	1	—

* Tabulations have also been provided from three observatories where Wiechert horizontal seismographs record movements in the directions NE-SW and NW-SE.

† The heavy pendulum at Zürich is included in this group.

Table II (appendix) is a summary of the tabulations for observatories at which the records were reasonably complete, and where the seismographs were sufficiently sensitive to show the changes in microseisms throughout the month. The data tabulated include the monthly means of amplitude and period for 1h., 7h., 13h. and 18h., the means for all hours and the maximum amplitudes. The type of seismograph is indicated by the initials shown in the first column of Table I. Occasionally when complete tabulations for January, 1930, were not available other information was supplied ; such information is set out immediately after the table. Figs. 4 to 7 show the amplitudes and periods of the microseisms at a number of observatories for the four hours daily throughout the month. The periods are expressed in seconds ; for the amplitudes the ratios of individual values to the monthly mean for the component are indicated.

§ 3—POSSIBLE ERRORS IN THE TABULATIONS OF MICROSEISMS DUE TO INSTRUMENTAL CAUSES

In considering the data of Table II the first question which arises is to determine how closely the results obtained from the various types of seismograph are comparable. Rough comparisons between the different types have suggested that the amplitudes computed from their records would generally be in agreement, but the results of the survey show that large discrepancies may occur, especially for very small amplitudes. The tabulations for Copenhagen and Strasbourg furnish direct comparisons between Galitzin, Milne-Shaw and Wiechert instruments. The monthly means of the amplitude and period of the microseisms recorded at these observatories are set out in Table III.

TABLE III—MEAN AMPLITUDES AND PERIODS OF MICROSEISMS AT COPENHAGEN AND AT STRASBOURG DURING JANUARY, 1930

Observatory	Type of seismograph	Free period			Damping ratio			N–S		E–W		Z	
		N–S	E–W	Z	N–S	E–W	Z	Amplitude	Period	Amplitude	Period	Amplitude	Period
		sec.	sec.	sec.				μ	sec.	μ	sec.	μ	sec.
Copenhagen	G	12·6	—	8	∞	—	∞	1·4	5·9	—	—	1·3	5·9
,,	M.S.	12	12	—	20	20	—	1·7	6·0	1·7	5·9	—	—
,,	W	9·6	9·6	5·6	4·3	4·4	4·2	0·7	5·6	0·9	5·6	0·7	5·5
Strasbourg	G	10·6	12·0	11·5	∞	∞	∞	5·8	6·2	3·6	6·2	1·9	6·2
,,	W	9·4	8·5	3·3	3·8	3·0	4·0	4·9	6·2	2·6	6·1	1·9	5·5

To Face P. 6

Plate III

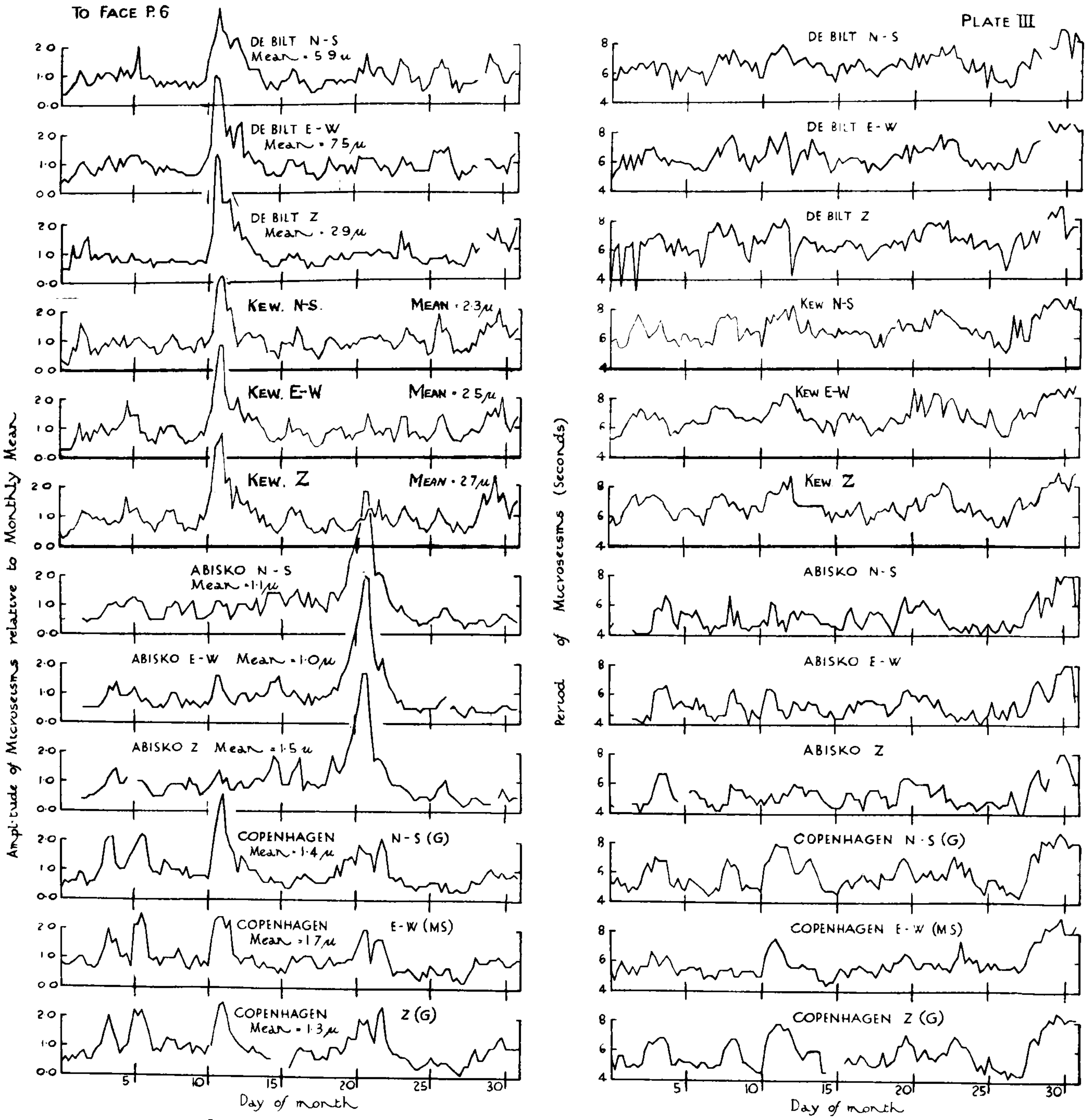

Fig 4. AMPLITUDE AND PERIOD OF MICROSEISMS JANUARY 1930.

(1171) Wt 2516, 768, 625, 1/34 G 921 C & R Co

PLATE IV

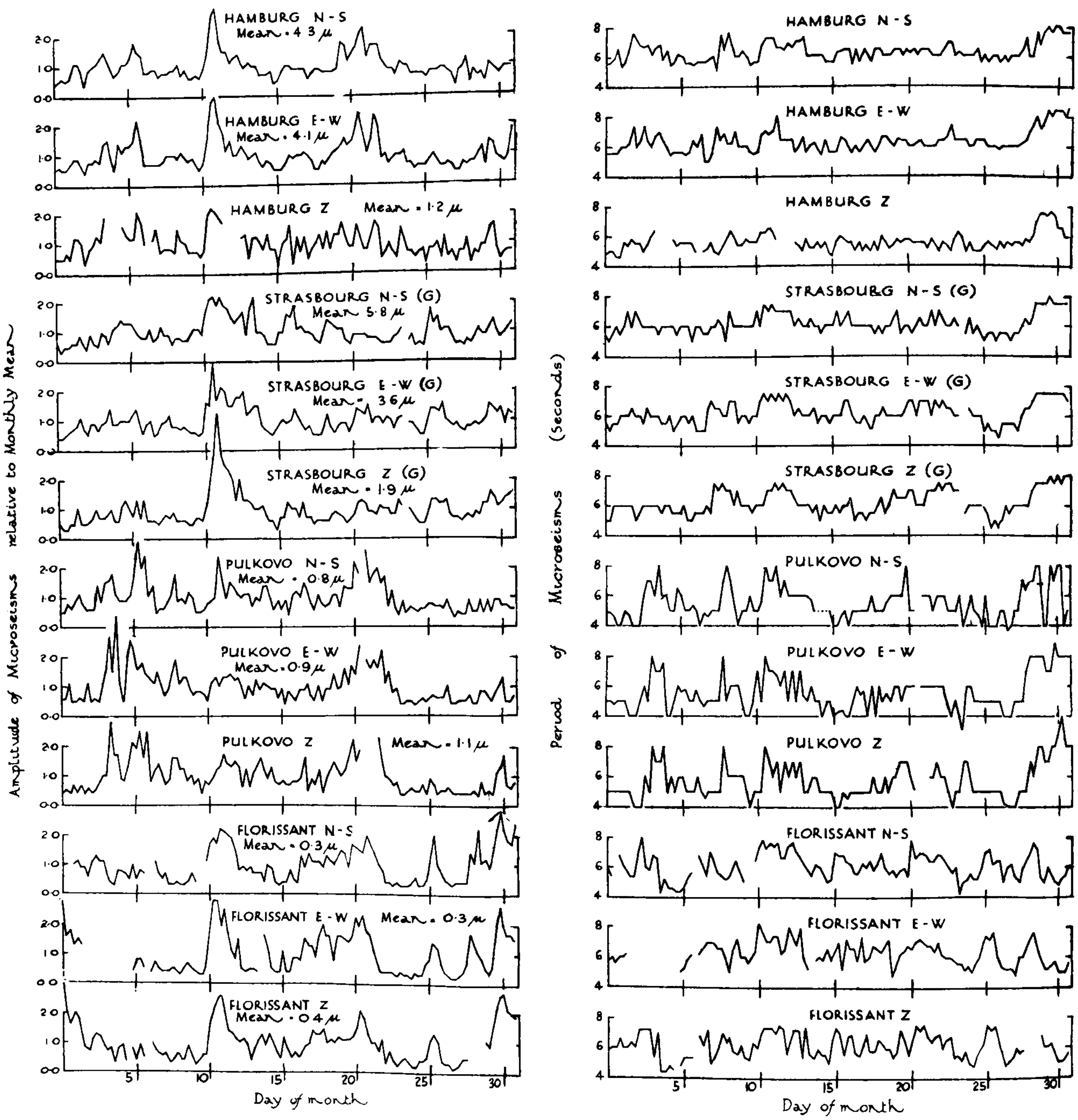

Fig 5 AMPLITUDE AND PERIOD OF MICROSEISMS. JANUARY 1930.

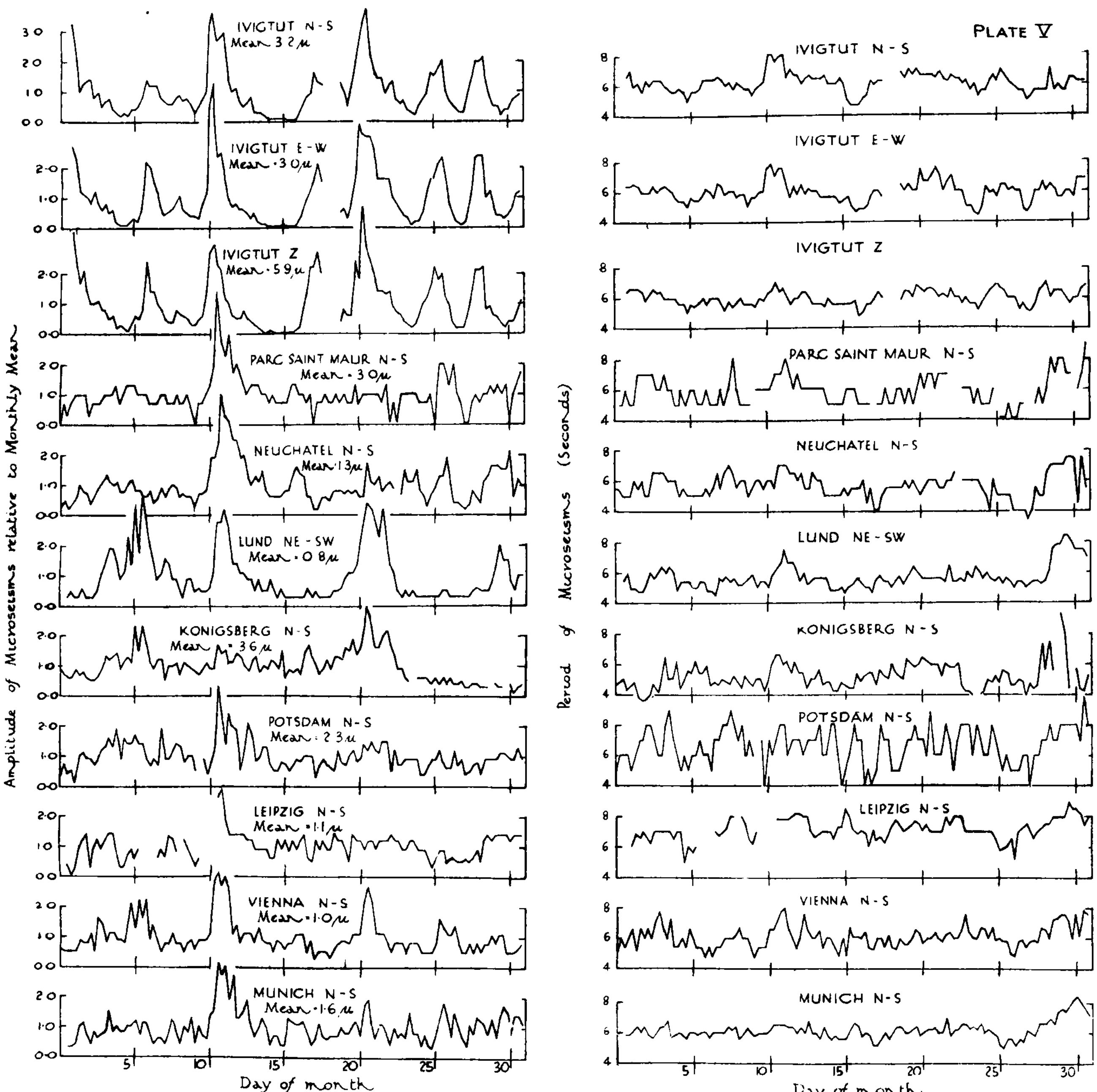

Fig 6 AMPLITUDE AND PERIOD OF MICROSEISMS. JANUARY 1930.

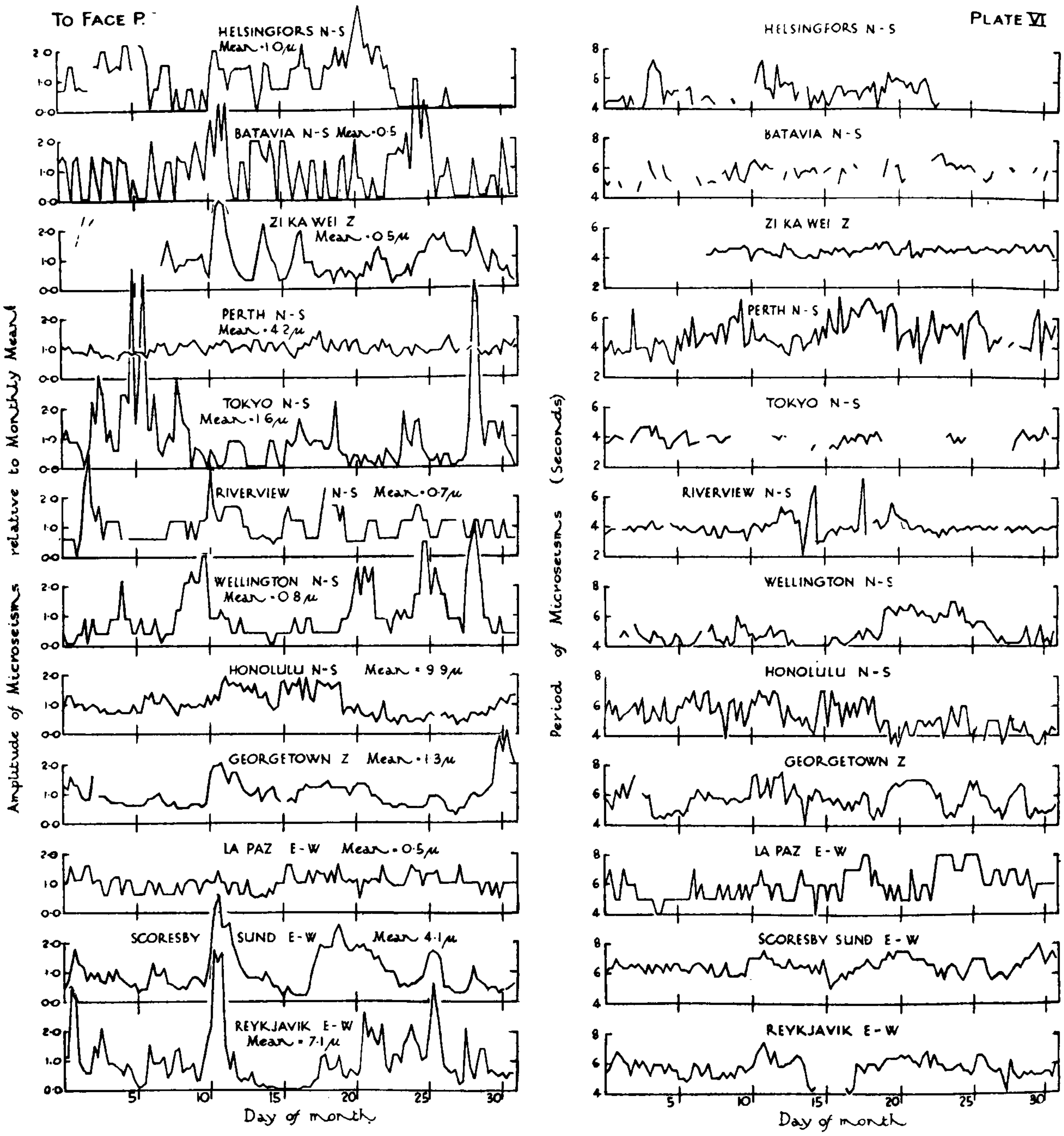

Fig. 7. AMPLITUDE AND PERIOD OF MICROSEISMS JANUARY 1930.

The periods of the N–S component microseisms on the Galitzin and Milne-Shaw records at Copenhagen are very nearly equal, and since the constants of the Milne-Shaw instruments at that observatory are only known approximately, the agreement between the amplitudes is about as good as can be expected. The discrepancies between the Galitzin and Wiechert microseisms are more serious and may be attributed to two causes—(i) differences between the free periods of the seismographs, and (ii) the effect of friction in reducing the amplitudes obtained from seismographs which record mechanically.

For harmonic motion the magnification of a seismograph depends upon the ratio of its free period to the period of the earth wave, so the amplitude recorded depends upon the period. Fig. 8 shows (a) harmonic earth movements with periods of 5 sec. and of 7 sec. and amplitudes 100μ, and how these would be reproduced in the records of the N–S Galitzin seismograph at Kew (b), and of the N–S and E–W Wiechert seismographs at Potsdam (c, d). In (b) and (c) the waves of period 7 sec. are recorded with the larger amplitudes, but for (d), a seismograph with a free period of only 6 sec., the 5 sec. earth waves would apparently be the larger. Thus, if during the 10 minutes centred at the hour the period of the microseisms varied from 5 sec. to 7 sec. while the amplitude was constant, the microseisms of 7 sec. would be selected for tabulation from the records of (b) and (c), but those of 5 sec. would be selected from (d). Generally this effect is only appreciable when the free period of the seismograph is less than about 7 or 8 sec. It is indicated in the tabulations for a number of observatories; for example, the mean periods of the horizontal microseisms at Strasbourg, Uccle and Hamburg are between 6 and 6½ sec., but the mean periods obtained from the short-period vertical seismographs at these observatories are about 5½ sec. As the free period of the seismograph diminishes the effect becomes larger, and it has been found that microseisms are scarcely perceptible in the records of Wood Anderson seismographs which may have a free period of 1 second or less. In fact these instruments have been designed to give a large magnification of the onsets of earthquake waves and of high-pitched oscillations, but not of the microseisms, of the longer period disturbances due to wind, etc., or of the seismic surface waves.

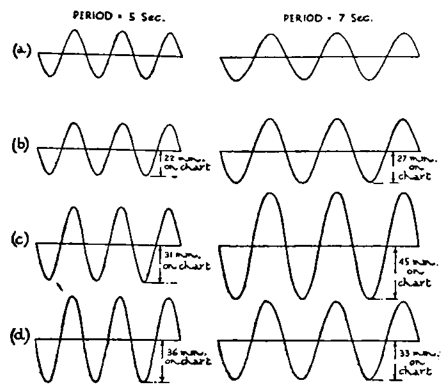

FIG. 8.—RECORDS FROM SEISMOGRAPHS HAVING DIFFERENT FREE PERIODS OF HARMONIC EARTH MOVEMENTS WITH PERIODS OF 5 SEC. AND 7 SEC.

(a) HARMONIC EARTH MOVEMENTS OF AMPLITUDE 100 μ.

(b) RECORD OF N-S GALITZIN SEISMOGRAPH AT KEW. $T_0=25{\cdot}5$ SEC., DAMPING $\infty : 1$.

(c) RECORD OF N-S WIECHERT SEISMOGRAPH AT POTSDAM. $T_0=10{\cdot}0$ SEC., DAMPING $3{\cdot}0 : 1$.

(d) RECORD OF E-W WIECHERT SEISMOGRAPH AT POTSDAM. $T_0=6{\cdot}0$ SEC., DAMPING $2{\cdot}5 : 1$.

Seismographs with mechanical registration are subject to friction arising in the bearings which carry the recording arms and between the stylus and the chart. The friction is determined regularly in the standardisation of the instruments, but is not generally taken into account in reduction of the measurements. Assuming that the friction is constant and always acts along the tangent to the curve traced out by the stylus, a formula has been developed by H. F. Reid (8) and independently by S.T. Nakamura (9) for computation of the earth movement which would correspond with a simple harmonic record. Early in the survey the amplitudes of microseisms at a number of observatories were computed from the Reid-Nakamura formula as well as from Wiechert's formula. The results obtained from the more complicated formula were very inconsistent. For example, at Copenhagen they agreed with the values from the Galitzin and Milne-Shaw seismographs more closely than the Wiechert amplitudes in Table III, but for Strasbourg the values obtained from the Reid-Nakamura formula were much too large. It appears likely from later investigations that the discrepancies arise if the friction is partially overcome by short-period oscillations superposed upon the microseisms. For the purpose of this survey the results obtained from Wiechert's formula have been retained, but it is realised that the amplitudes must be too small. In general the amplitudes for seismographs which record mechanically, especially for those with a free period less than about $7\frac{1}{2}$ sec., must be regarded as less reliable than those obtained from longer-period seismographs with photographic registration. On the other hand the results may be of value in showing the day-to-day changes in microseismic activity, even though the amplitudes and periods are underestimated.

The most satisfactory records for the present research are those obtained from Galitzin or Milne-Shaw seismographs. The free period of the Milne-Shaw seismograph varies with the amplitude of the swing, presumably owing to friction at the boom point. In standardization the pendulum is set swinging and the mean period is measured for 10 oscillations commencing from an amplitude of ± 10 mm.; the periods usually employed are 10 or 12 sec. Some experiments were made with a seismograph of this type recording the N–S component beside the Galitzin pendulums at Kew during the summer of 1932. The period diminished from 10·5 sec. for amplitudes ± 10 mm. to about 10·2 sec. for very small amplitudes. The period found in the routine tests may therefore be used for reducing the amplitudes of microseisms. While the Milne-Shaw seismograph was in operation the amplitudes of the microseisms recorded, or of those shown in the corresponding Galitzin seismograms, did not exceed a few tenths of a millimetre, and on comparison no systematic difference could be detected between the amplitudes computed for the two types of instrument.

§ 4—COMPARISON OF THE N–S AND E–W COMPONENTS OF THE MICROSEISMS

A comparison is given in Table IV of the microseisms recorded by the N–S and E–W seismographs at observatories where both these components are available; the tabulations show the ratios of the N–S to E–W component for monthly mean periods and amplitudes and the ratios of the maximum amplitudes. At each of the observatories except four the mean periods of the N–S and E–W microseisms agree to within 5 per cent. At Victoria the difference is only slightly greater than 5 per cent, and the ratios for the other three abnormal stations (Potsdam, Apia and Pasadena) may be attributed to differences between the free periods of the N–S and E–W seismographs. For comparisons between the components the maximum amplitudes are less reliable than the means; the latter differ by less than 15 per cent at 24 of the 34 stations represented, and by less than 25 per cent at all of the stations except Potsdam, Strasbourg and Pasadena. The discrepancies at Potsdam and Pasadena are explained by the differences between the periods of the seismographs.

Dot diagrams representing points of simultaneous values of the N–S and E–W amplitudes at Reykjavik, Kew and Potsdam, appear in Fig. 9. These diagrams show that for individual hours there may be large differences between the amplitudes of the two components. The apparent excess of the N–S component at Potsdam has already been explained. The diagrams for Reykjavik and Kew show that either component may be the greater; the amplitudes at Reykjavik are more scattered than those at Kew, indicating greater differences between the components at the former observatory.

The remarkable difference between the two components at Strasbourg has been noted by other investigators. J. Lacoste (10) gives the ratios of the yearly mean amplitudes (derived from the Galitzin records) from 1927 to 1929 as 1·2, 1·4 and 1·4. B. Gutenberg, who has published (11) the ratios for various stations of of the N–S to E–W amplitudes during a number of spells of large microseisms from 1911 to 1914, finds that the mean ratio at Strasbourg varied from 1·0 to 1·4. Gutenberg thought that there was a tendency for the E–W component to be the greater in northern and southern Europe, and for the N–S component to be the

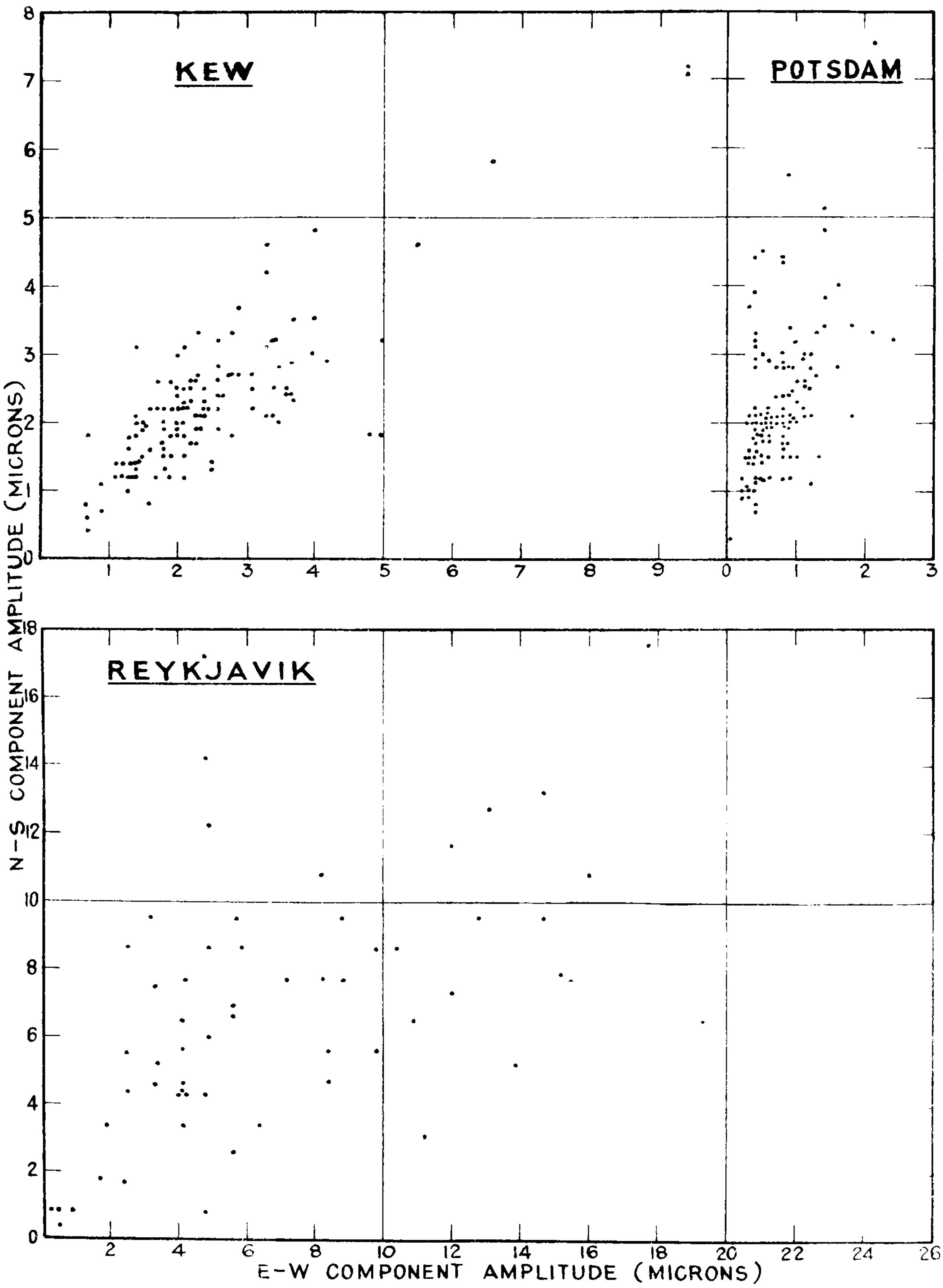

FIG. 9 COMPARISON OF N-S & E-W AMPLITUDES, JANUARY 1930.

COMPARISON OF HORIZONTAL AND VERTICAL AMPLITUDES. JANUARY 1930.

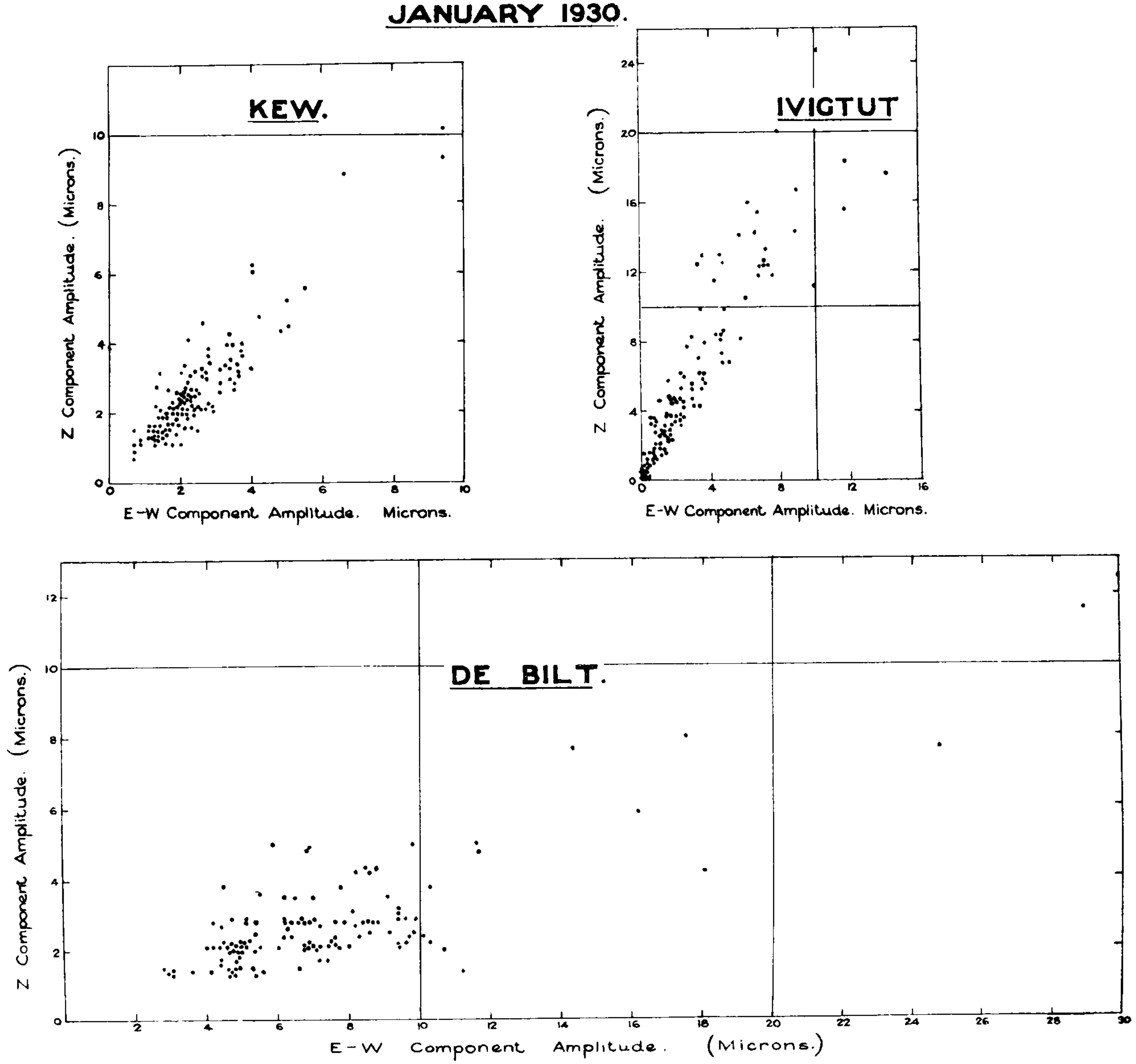

FIG. 13.

greater in central Europe. More recently he has examined the distribution of microseisms in North America, (12) and finds that the ratio of N–S to E–W amplitudes is 0·8 at Victoria, 0·9 at Chicago and Ottawa, 1·0 at Tuscon, 1·1 at Harvard and 1·2 at Florissant ; he concludes that " the number and quality of the observations are not yet sufficient to yield definite results." The ratios of the amplitudes given in Table IV, both for Europe and for North America, are generally in good agreement with the ratios given by Gutenberg.

The anomaly at Strasbourg can be explained from the theory of Rayleigh waves propagated through rock covered by a layer of sedimentary material. According to the results given in one of the earlier papers (6) the larger movements would occur with the layers of greater thickness or of weaker material. The formulæ used depend upon the assumption that the horizontal extent of the material is very large compared with the wave length of the microseisms.* This assumption does not hold for Strasbourg which is situated (Fig. 10) between the Vosges and the

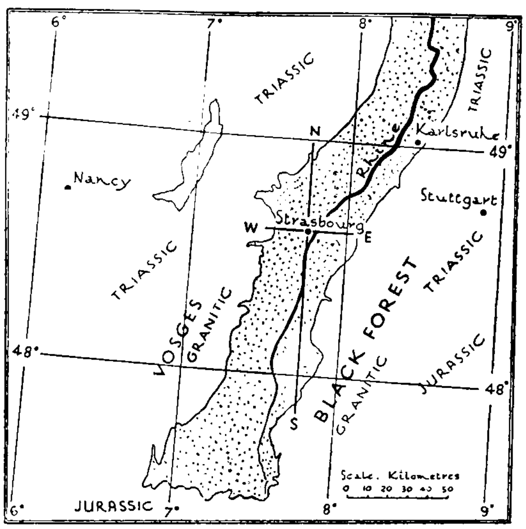

FIG. 10.—DISTRIBUTION OF STRATA AROUND STRASBOURG.

QUATERNARY FORMATIONS STIPPLED.

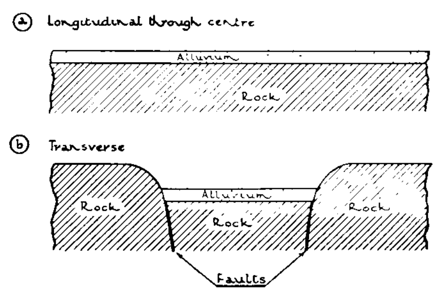

FIG. 11.—SECTIONS OF RIFT VALLEY.

Black Forest in a great rift valley which runs from south-south-west to north-north-east. The weakest alluvial deposits are along the valley, the longitudinal and transverse sections being roughly represented in Fig. 11 ; the longitudinal extent is about 300 Km., but the breadth (some 25 Km.) is comparable with the microseismic wave lengths and the E–W amplitudes are affected less than the N–S amplitudes. The smaller differences between the horizontal amplitudes at other observatories may be due to asymmetry in the stratification. As an example the distribution of strata around Kew is given in Fig. 12. In this case, with the London clay lying on the great chalk syncline between the Chiltern Hills and the North Downs, the weaker deposits extend further from west to east than from north to south, and the E–W mean amplitude is the greater.

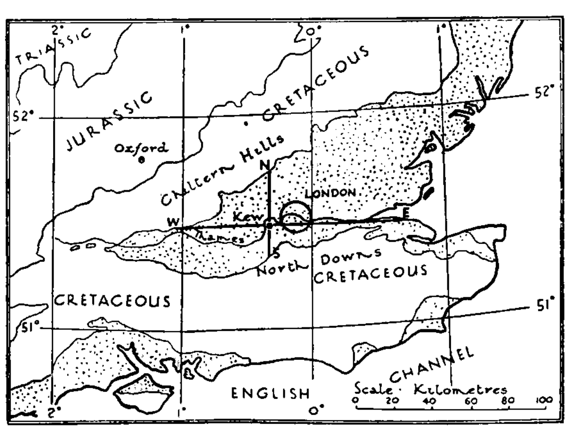

FIG. 12.—DISTRIBUTION OF STRATA AROUND KEW. TERTIARY AND QUATERNARY FORMATIONS STIPPLED.

* About 18 Km. for Rayleigh waves of period 2π seconds.

TABLE IV—COMPARISON OF THE N–S AND E–W COMPONENTS AT VARIOUS OBSERVATORIES, JANUARY, 1930

Observatory	Seismograph free period N–S	Seismograph free period E–W	Ratio of mean periods. N/E	Ratio of mean amplitudes. A_N/A_E	Ratio of maximum amplitudes. A_N/A_E	Observatory	Seismograph free period N–S	Seismograph free period E–W	Ratio of mean periods. N/E	Ratio of mean amplitudes. A_N/A_E	Ratio of maximum amplitudes. A_N/A_E
	sec.	sec.					sec.	sec.			
De Bilt	24·2	25·1	1·0	0·8	0·7	Zürich	3·0	3·0	1·0	1·0	1·0
Kew	25·5	24·7	1·0	0·9	0·8	Helsingfors ..	12	12	1·0	1·0	1·0
Uccle	24·5	24·5	1·0	1·2	0·7	Pulkovo ..	14·8	13·4	1·0	0·9	0·8
Parc Saint Maur	11·5	11·6	1·0	1·1	1·4	Kučino	23·8	22·6	1·0	1·0	1·0
Neuchatel ..	2·8	2·8	1·0	1·1	1·0	Batavia ..	6·8	6·6	1·0	1·0	0·8
Abisko	11·8	11·9	1·0	1·1	1·1	Tokyo	12·0	12·0	1·0	0·8	1·4
Uppsala	8·4	8·8	1·0	1·1	1·3	Riverview ..	8·5	9·4	1·0	0·9	0·7
Copenhagen (MS).	12	12	1·0	1·0	1·4	Apia	7·4	9·0	0·9	1·2	1·5
,, (W).	9·6	9·6	1·0	0·8	0·8	Wellington ..	10·3	9·8	1·0	0·8	0·8
Königsberg ..	9·1	8·8	1·0	1·0	1·1	Honolulu ..	12	12	1·0	1·1	0·9
Hamburg ..	9·2	9·9	1·0	1·0	1·1	Victoria.. ..	12·0	12·0	0·9	0·8	0·9
Potsdam ..	10·0	6·0	1·3	2·9	3·1	Pasadena ..	4·5	10	0·9	0·4	0·5
Göttingen ..	10·7	12·7	1·0	0·8	0·5	Florissant ..	12	12	1·0	1·0	1·0
Leipzig	10·1	9·7	1·0	1·0	1·1	Ottawa	12·0	12·0	1·0	1·0	1·3
Strasbourg (G) ..	10·6	12·0	1·0	1·6	1·2	Harvard ..	12	12	1·0	1·1	1·0
,, (W) ..	9·4	8·5	1·0	1·9	1·3	Ivigtut	12·2	12·4	1·0	1·1	0·8
Vienna	9·4	11·2	1·0	1·1	0·9	Scoresby Sund*	11·7	13·1	1·0	1·1	1·0
Munich	9·0	8·9	1·0	1·1	0·9	Reykjavik* ..	6·1	6·7	1·0	0·9	0·7

* Complete data for both components throughout the month are not available; the ratios entered refer to the days when both components were recorded.

§ 5—COMPARISON OF THE HORIZONTAL AND VERTICAL COMPONENTS OF THE MICROSEISMS

As a preliminary to the comparison of the horizontal and vertical components it is necessary to compute the horizontal motion from the tabulated amplitudes of the N–S and E–W microseisms. Very frequently the parallelogram law $A_H^2 = (A_N^2 + A_E^2)$ has been used for this purpose, but since the tabulated amplitudes for the N–S and E–W components scarcely ever occur in the same group of microseisms (see Fig. 2) the formula gives values of A_H which are too large. The suggestion has been made in (6) that it would be simpler and probably more accurate to take the larger of the north and east tabulated amplitudes as an approximation to the horizontal amplitude. The tabulations only indicate that the horizontal amplitude lies between certain values expressed by the formula

$$(A_N^2 + A_E^2)^{\frac{1}{2}}/2^{\frac{1}{2}} \leq A_H \leq (A_N^2 + A_E^2)^{\frac{1}{2}}$$

With no systematic difference between the N–S and E–W components the monthly mean horizontal amplitude should be computed from the larger of the amplitudes tabulated for each hour. In view of the uncertainties of the tabulations and the general similarity between the variations of the components it was decided that no useful purpose would be served by these additional data, and the larger of the N–S and E–W monthly means has been taken as the horizontal mean amplitude.

The ratios of horizontal to vertical components are set out in Table V. At Uccle, Hamburg and for the Wiechert seismograms at Strasbourg, the period tabulated for the vertical component microseisms is less than that of the horizontal component owing to the short free period of the vertical seismograph; the ratios of the amplitudes for these observatories, and for Göttingen and Ivigtut, may also be affected. Elsewhere the ratios of the amplitudes, A_H/A_Z, vary from 0·6 to 3; Gutenberg found that in Europe $(A_N^2 + A_E^2)^{\frac{1}{2}}/A_Z$ was generally between 1 and 4 so the results are in agreement.

TABLE V—COMPARISON OF THE HORIZONTAL AND VERTICAL COMPONENTS AT VARIOUS OBSERVATORIES. JANUARY, 1930

(The larger of the N-S and E-W components is taken as the horizontal.)

Observatory	Type of seismograph		Seismograph free period		Ratio of mean periods	Ratio of mean amplitudes	Ratio of maximum amplitudes
	H	*Z*	*H*	*Z*	H/Z	A_H/A_Z	A_H/A_Z
De Bilt	G	G	25·1	12	1·0	2·6	2·4
Kew	G	G	24·7	12·9	1·0	0·9	0·9
Uccle	G	W	24·5	4·8	1·2	2·0	1·7
Abisko	G	G	11·8	11·6	1·0	0·7	0·7
Copenhagen ..	G	G	12·6	8	1·0	1·1	1·5
,, ..	W	W	9·6	5·6	1·0	1·3	1·0
Hamburg	W	W	9·2	6·0	1·1	3·6	5·0
Göttingen	W	W	12·7	4·0	1·0	0·5	1·2
Strasbourg ..	G	G	10·6	11·5	1·0	3·1	1·5
,, ..	W	W	9·4	3·3	1·1	2·6	2·0
Pulkovo	G	G	13·4	14·0	1·0	0·9	1·1
Kučino	G	G	22·6	11·1	1·0	0·9	1·0
Florissant	G	G	12	12	1·0	0·7	0·6
Ivigtut	W	W	12·2	5·3	1·0	0·5	0·7

The computations of the effect of a superficial layer upon Rayleigh waves (6), indicate that the horizontal amplitudes of waves with the period of the microseisms are affected more than the vertical amplitudes. Thus the ratio A_H/A_Z is greater than that for simple Rayleigh waves (0·68). The ratio depends upon the wave length and upon the composition and thickness of the layer; the largest value obtained in the computations was about $1\frac{1}{3}$ for waves of period 2π seconds propagated through granite covered by a layer of clay 1 Km. in thickness. Presumably with weaker material in a thinner layer the ratio might be greater and the ratio of A_H/A_Z at De Bilt ($2\frac{1}{2}$) on diluvium sand seems reasonable.

The effect of the superficial material varies with the wave length, being greater for the waves of shorter periods. To determine whether such variations were indicated in the microseismic amplitudes of January, 1930, the values of A_H/A_Z obtained from the Galitzin seismographs at De Bilt, Kew and Abisko, were classified for periods 4·0–4·9, 5·0–5·9, 6·0–6·9, 7·0–7·9, 8·0–8·9 sec. and the median of each group was selected. The monthly mean amplitudes and the medians for the various periods are given in Table VI; the figures in brackets indicate the number of observations from which the medians were obtained.

TABLE VI—MEAN AMPLITUDES OF MICROSEISMS AND MEDIANS OF A_H/A_Z FOR DIFFERENT PERIODS. JANUARY, 1930

Observatory	Component taken for A_H	Mean A_H	Mean A_Z	Median of A_H/A_Z for periods :—				
				4·0–4·9 sec.	5·0–5·9 sec.	6·0–6·9 sec.	7·0–7·9 sec.	8·0–8·9 sec.
		μ	μ					
De Bilt ..	E-W	7·5	2·9	— —	3·2 (43)	2·9 (48)	2·3 (23)	1·9 (8)
Kew ..	E-W	2·5	2·7	— —	1·0 (17)	0·9 (58)	0·9 (30)	0·8 (18)
Abisko ..	N-S	1·1	1·5	0·7 (58)	0·7 (39)	0·7 (14)	0·7 (2)	0·8 (4)

The mean ratio A_H/A_Z is 2·6 at De Bilt on diluvium sand, 0·9 at Kew where the uppermost strata are of London clay and chalk, and 0·7 at Abisko on schist with a layer 5 m. thick of very hard morainic material. There are systematic variations of A_H/A_Z with the period at De Bilt and, to a lesser extent at Kew; the ratio at Abisko agrees with that for simple Rayleigh waves and does not vary with the period. The microseisms at these observatories may be taken as examples of the disturbances for weak formations, for consolidated formations and for rock respectively. Thus, although the material in the earth's crust is very heterogeneous with many layers of varying materials and thicknesses, and the stratification may not be horizontal, the hypothesis of a single uniform layer makes the observed values of A_H/A_Z much more comprehensible than they were from the theory of simple Rayleigh waves.

Dot diagrams for the amplitudes at Ivigtut, de Bilt and at Kew, of the larger horizontal component and of the vertical component appear in Fig. 13 (facing p. 9). The scatter is less than that shown in Fig. 9 representing the two horizontal components, suggesting that the agreement between the horizontal component with the larger mean amplitude and the vertical component is closer than that between the two horizontal components. A similar result is shown by the correlation coefficients between the amplitudes of the different components at Kew (where the mean amplitudes are $A_N = 2{\cdot}3\mu$, $A_E = 2{\cdot}5\ \mu$ and $A_Z = 2{\cdot}7\ \mu$,) the coefficients being 0·82 between N–S and E–W, 0·85 between N–S and Z, and 0·92 between E–W and Z.

§ 6—THE DIURNAL VARIATION OF MICROSEISMS

A critical examination of the tabulated amplitudes and periods of the microseisms recorded at Kew and at Eskdalemuir (13) indicated that there were no regular diurnal variations in the microseisms at either of these observatories. On the other hand in both the horizontal components at Graz there are well marked diurnal variations, the amplitudes and periods being greatest around midday. Accordingly it is of interest to find what further information regarding the diurnal variations is available from the tabulations for January, 1930. The hourly means of Table II, see appendix, show that at most of the observatories the changes in the mean amplitude and period from hour to hour are small, and with data only covering a single month, these variations must be regarded as fortuitous unless they are confirmed from the other components or from adjacent observatories. The tabulations suggest that, although widespread, the microseisms do not fluctuate sympathetically over the whole world, consequently there is a likelihood that the diurnal variations would follow local mean time rather than G.M.T. The diurnal variations are much more concordant on this hypothesis, and local time has generally been used for this section. The following information regarding the diurnal variation in different localities is obtained from Table II.

Central Europe. The variations at Graz, with maxima in the middle of the day and minima in the night, are characteristic of practically all the observatories in central Europe. They are shown in the amplitudes for all the German observatories except Göttingen where the microseisms are small, from France to Holland, and at Lund, Vienna and Zagreb. The records from Hamburg, Munich and Vienna have been examined at Kew Observatory and it was noticed that the diurnal variation in the amplitudes can be recognised on most days from a cursory inspection of the seismograms. The variations in the mean periods are less systematic than those in the amplitudes. In Switzerland the changes from hour to hour are small.

Great Britain. The variations in amplitude and period at the seven British observatories are small, and with the extreme values fairly evenly distributed among the four hours, there is no evidence in favour of diurnal variations.

Batavia. The tabulated amplitudes for both horizontal components show systematic variations on nearly all the days, with the largest microseisms at 8h. or 14h., the least at 1h. (L.M.T.). The amplitudes at 1h. were frequently too small for the periods to be estimated, so the mean periods for that hour have been computed from the days having the larger amplitudes ; the longer mean periods at 1h. are in accordance with the well known tendency for longer periods to be associated with the larger amplitudes.

Perth (*West Australia*). The variation in amplitude is similar to that at Batavia. The amplitudes and periods at 9h. and 15h. are appreciably greater than those at 21h. and 2h. (L.M.T.).

Tokyo. For both components the mean amplitudes at 10h. and 16h. are greater than those at 22h. and 3h. ; the smallest amplitudes and the shortest periods are those at 3h. (L.M.T.).

North America. The mean amplitudes from hour to hour are very uniform, and except possibly at Harvard, there are no indications of regular variations. The largest amplitudes at Harvard are from 8h. to 13h. (L.M.T.).

Ivigtut. The variations in mean period are small ; the mean amplitudes at 15h. and 22h. are generally larger than those at 4h. and 10h. (L.M.T.)

Scoresby Sund. 17h. shows the largest amplitude and the longest period, but the ranges of the variations are small.

Reykjavik. No diurnal variations are shown in the periods, but for the amplitudes there are large variations. For the N–S component the amplitudes range from 6·1μ at 0h. to 7·4μ at 6h., and for the E–W component from 5·4 μ at 0h. to 8·4 μ at 12h. and 17h. (L.M.T.) ; thus the minima occur at the same time but the maxima are irregular.

The most pronounced diurnal variations in the amplitudes are those in central Europe, Batavia, Perth, Tokyo and Reykjavik, and in each case the minima occur around midnight and the maxima during the day. The variations for a number of observatories are plotted in Fig. 14 ; the left side of the diagram refers to some of

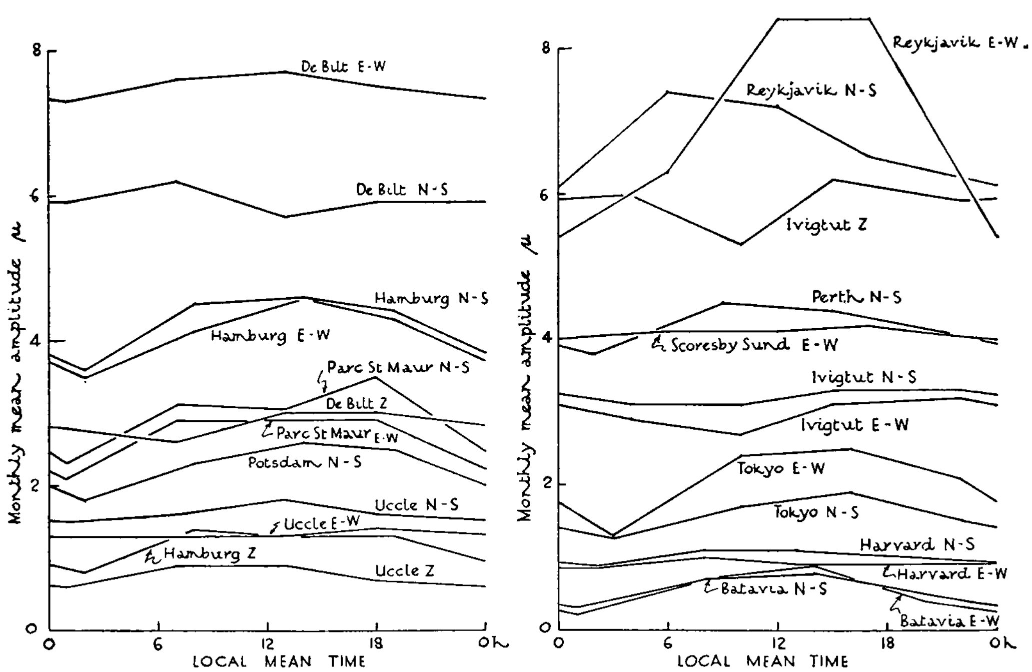

FIG. 14.—DIURNAL VARIATION IN AMPLITUDE OF MICROSEISMS ; ALL DAYS OF JANUARY, 1930.

the European stations, the right to those in other regions. The curves for Batavia are more regular than those elsewhere and there is very little difference between the two components. The range of the diurnal variation at Batavia is equal to or greater than the mean amplitude ; with this exception the range does not exceed about half of the mean amplitude. The E–W component at Reykjavik has a very large range, but the range for the same component at Scoresby Sund is very small.

To determine whether the diurnal variation is a feature of all the days, or whether it occurs only on the days of large or of small disturbance, the mean amplitudes and periods of five " disturbed " days (" D "), and of five " quiet " days (" Q "), have been computed for each of the four hours at a number of observatories; the means are set out in Table VII, and the amplitudes are plotted in Fig. 15. The

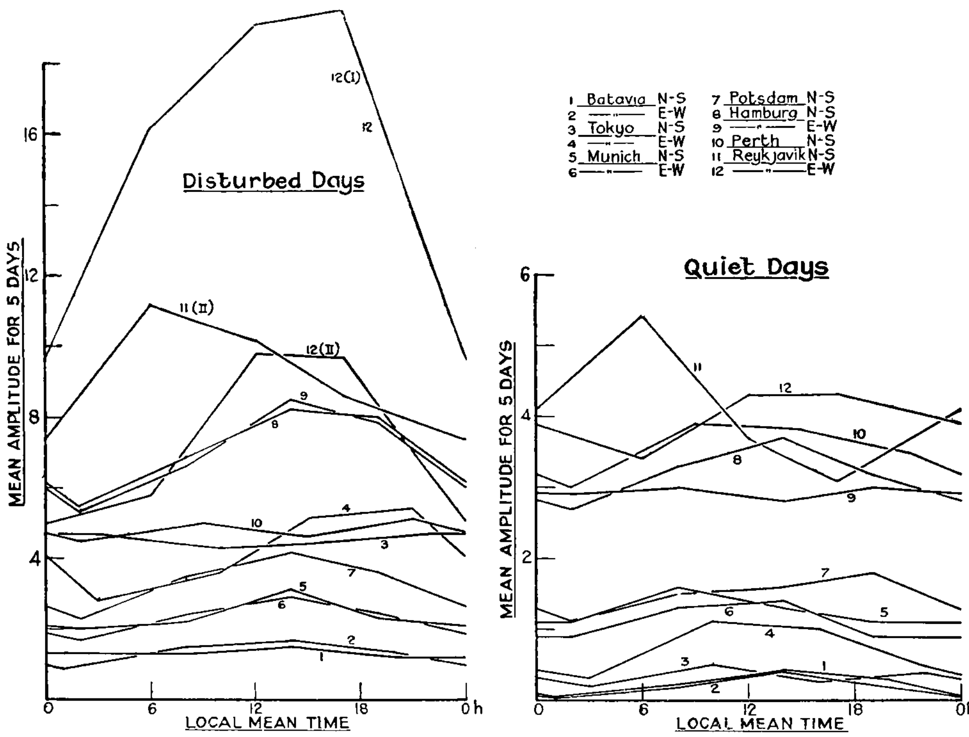

FIG. 15.—DIURNAL VARIATION IN AMPLITUDE OF MICROSEISMS; "DISTURBED" AND "QUIET" DAYS, JANUARY, 1930.

choice of days for inclusion in the groups was made from the occasions of large or small amplitudes in Figs. 4–7. The same " D " and " Q " days have been selected for Hamburg, Potsdam and Munich, but the days selected elsewhere differ from station to station.

For the E–W component at Reykjavik two sets of " D " days are given: (I) selected from the E–W amplitudes for the whole month, (II) the days chosen from the N–S tabulations which were only available from the 17th to the end of the month; it should be noted that no days are common to these two groups.

Comparison of the mean periods on the " D " and " Q " days shows that in each case the mean of the " D " days was longer than that of the " Q " days. The variations in period for the " Q " days are generally uncertain since the period cannot be measured for very small amplitudes. Averages of the amplitudes and periods at Hamburg, Potsdam and Munich for the " D " and " Q " days, respectively, are given at the bottom of Table VII; for the days in each group the mean amplitudes and periods are greatest around midday. The mean amplitude of the " D " days is only a little larger than that of the " Q " days at Perth, it is about twice as great in Germany, and becomes much larger at Batavia and Tokyo. The curves, being obtained from so few values, are more irregular than those for " all " days, but they show that the diurnal variations on the " D " days and on the " Q " days are similar, with the minima at night and maxima in the daytime. The N–S component at Reykjavik is most anomalous, with an earlier maximum at 6h. on both " D " and " Q " days, and with the minimum for " Q " days at 17h. (L.M.T.). For the E–W component at Reykjavik the most prominent features of the " D " days are

TABLE VII—MICROSEISMS ON "DISTURBED" AND "QUIET" DAYS. JANUARY, 1930

(Observations at 1h, 7h, 13h and 18h, G.M.T.)

Observatory	Zone	Component	Type of day	Mean amplitude						Mean period				
				1h	7h	13h	18h	Mean	Range/Mean	1h	7h	13h	18h	Mean
				μ	μ	μ	μ	μ		sec.	sec.	sec.	sec.	sec.
Hamburg ..	1	N-S	D	5·5	6·9	8·2	8·0	7·1	0·4	6·4	6·5	6·4	6·5	6·5
			Q	2·7	3·3	3·7	3·2	3·2	0·3	6·0	5·8	5·9	6·1	5·9
,, ..		E-W	D	5·4	6·6	8·5	7·9	7·1	0·4	6·1	6·7	6·4	6·4	6·4
			Q	2·9	3·0	2·8	3·0	2·9	0·1	5·8	5·7	6·1	5·8	5·9
Potsdam ..	1	N-S	D	2·3	3·4	4·2	3·6	3·4	0·6	7·0	6·2	7·8	7·0	7·0
			Q	1·1	1·5	1·6	1·8	1·5	0·5	6·0	6·4	6·4	5·6	6·1
Munich ..	1	N-S	D	2·0	2·2	3·1	2·3	2·4	0·5	6·2	6·3	6·5	6·1	6·3
			Q	1·1	1·6	1·3	1·1	1·3	0·4	5·7	6·0	6·1	5·8	5·9
,, ..		E-W	D	1·7	2·4	2·9	2·4	2·3	0·5	6·1	6·2	6·2	6·2	6·2
			Q	0·9	1·3	1·4	0·9	1·1	0·5	5·5	5·9	5·6	5·6	5·7
Batavia ..	7	N-S	D	1·3	1·5	1·2	1·3	1·3	0·2	6·3	6·1	6·0	6·1	6·1
			Q	0·2	0·4	0·2	0·0	0·2	2·0	5·5	5·1	5·5	—	5·4
,, ..		E-W	D	1·5	1·7	1·3	0·9	1·3	0·6	5·8	5·8	5·6	6·2	5·9
			Q	0·2	0·4	0·3	0·0	0·2	2·0	5·5	5·2	5·3	—	5·3
Perth ..	8	N-S	D	5·0	4·6	5·1	4·5	4·8	0·1	6·0	4·7	5·3	5·8	5·5
			Q	3·9	3·8	3·5	3·0	3·5	0·3	4·8	3·7	4·2	3·8	4·1
Tokyo ..	9	N-S	D	4·3	4·5	4·7	4·7	4·5	0·1	3·9	4·0	4·2	3·9	4·0
			Q	0·5	0·3	0·4	0·2	0·3	1·0	—	—	—	—	—
,, ..		E-W	D	3·6	5·1	5·4	2·8	4·2	0·6	4·0	4·2	4·2	3·8	4·0
			Q	1·1	1·0	0·5	0·3	0·7	1·1	4·0	4·1	3·6	3·6	3·8
Reykjavik ..	23	N-S	D (II)	7·4	11·2	10·2	8·6	9·3	0·4	5·9	6·0	6·0	5·8	5·9
			Q	4·1	5·4	3·7	3·1	4·1	0·6	5·5	5·4	5·4	5·5	5·5
,, ..		E-W	D (I)	9·6	16·1	19·1	19·6	16·1	0·6	5·6	6·0	6·2	6·4	6·1
			D (II)	5·0	5·8	9·8	9·7	7·6	0·6	5·9	5·8	5·7	5·7	5·8
			Q	3·9	3·4	4·3	4·3	4·0	0·2	5·6	5·4	4·9	5·2	5·3
Means of Hamburg, Potsdam and Munich (both components)			D	3·4	4·3	5·4	4·8	4·5	0·4	6·4	6·4	6·7	6·4	6·5
			Q	1·7	2·1	2·2	2·0	2·0	0·3	5·8	6·0	6·0	5·8	5·9

Days selected.	"D."	"Q."
Hamburg, Potsdam and Munich	11, 12, 20-22.	1, 15-18.
Batavia	11, 12, 14, 24, 25.	3, 6, 13, 19, 22.
Perth	7, 9, 12, 17, 18.	2-6.
Tokyo	3, 5, 6, 8, 29.	20-22, 26, 27.
Reykjavik	(I) 1, 10, 11, 24, 26. (II) 18, 19, 21, 25, 29.	17, 23, 27, 30, 31.

the maximum from 11h. to 17h. and the midnight minimum; they are shown in each of the curves I and II. The curves for the two components are in close agreement at Hamburg, Munich and Batavia, and on "Q" days at Batavia. The range of the diurnal variation is about half of the mean amplitude in Europe, and the difference between the "D" and "Q" days is small. At Batavia, Perth and Tokyo the ratio of range to mean is much greater on the "Q" days than on the "D" days.

The occurrences at each station of amplitudes in any component at least twice as large as the monthly mean are tabulated in § 7. The incidence of these large amplitudes at the various observatories supports the diurnal variations, the frequencies for the different hours (L.M.T.) being :—

Central Europe (16 observatories)	39 (2h.),	65 (8h.),	66 (14h.),	55 (19h.).
Batavia	3 (1h.),	11 (8h.),	12 (14h.),	4 (20h.).
Tokyo	3 (3h.),	5 (10h.),	5 (16h.),	6 (22h.).
Ivigtut	5 (4h.),	5 (10h.),	7 (15h.),	9 (22h.).
Reykjavik	4 (0h.),	3 (6h.),	6 (12h.),	4 (17h.).

The variations found for central Europe and for Batavia are very strongly brought out in these frequencies.

Gutenberg (11) has published the amplitudes of the microseisms at a number of observatories for twelve hours daily from January 31 to February 4, 1914, and from March 25 to 28, 1914, but he does not examine the data for diurnal variation. I have computed the diurnal variations at the 24 observatories which had complete records from two or more components during these intervals, expressing the hourly amplitudes as percentage departures from the means, and smoothing by the usual process of taking overlapping groups of three and giving double weight to the middle value. The 1914 data have been averaged according to the zones, the mean diurnal variations for 9 observatories in zone 0 and for 11 observatories in zone 1 being given in Fig. 16. The first harmonic components are :—

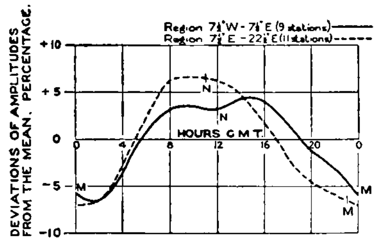

FIG. 16.—MEAN DIURNAL VARIATION IN AMPLITUDE OF MICROSEISMS, JANUARY 31 TO FEBRUARY 4, 1914, AND MARCH 25–28, 1914.

Zone 0. $5{\cdot}2 \sin (15t + 259°)$.

Zone 1. $7{\cdot}1 \sin (15t + 287°)$.

The maxima occur at 12h. 44m. G.M.T. for zone 0 and at 10h. 52m. G.M.T. for zone 1 ; consequently the phase difference is 1 hr. 52 min. if they are expressed in G.M.T., and only 52 min. if local time is used. For Strasbourg in zone 1 Lacoste finds (14) that the first harmonic component (computed from the horizontal Galitzin seismograms of November, 1927, to March, 1928) has a range of 2·8 per cent of the mean and phase angle 297°.

The diurnal variations found in the previous paragraphs, if genuine, apparently indicate that the microseismic oscillations can be generated on land, since (as far as is known) the larger sea waves are not subject to diurnal variations. Consequently it is necessary to examine whether the changes are of geophysical origin or whether they can be explained from local or instrumental causes. The diurnal variations of temperature are not likely to affect the seismographs, since these instruments are usually housed in a room where the temperature is very nearly constant, neither can such changes of temperature, within a few centimetres of the surface influence the microseismic oscillations. Noticing that the most prominent diurnal variations have been obtained at observatories with Wiechert seismographs, F. J. W. Whipple has suggested (15) that with mechanical registration the friction between the stylus and chart may change regularly, being lessened during the day when there are very rapid oscillations due to traffic, etc. The diurnal variations would be greatest at observatories subject to these influences ; examples supporting this suggestion are found at Copenhagen where with little disturbance near the seismographs there are no diurnal variations, and at Hamburg where traffic passes near the observatory and the variations are large.

§ 7—THE INCIDENCE AND DISTRIBUTION OF " MICROSEISMIC STORMS "

The data obtained from this survey show how in some regions the microseisms are never greater than a few tenths of a micron, but in others they may be very much larger. The monthly means are unsuitable for examining the variation in amplitude from place to place, for there were several spells of large microseisms during the month which affected different localities. The areas affected by these " microseismic storms " are indicated by Table VIII ; the entries for each observatory show the hours when the amplitude of either component was at least twice the monthly mean. More detailed tabulations, giving several ratios of the amplitudes to the means, have been attempted, but proved unsatisfactory owing to uncertainties in the mean amplitudes from seismographs with mechanical registration. The incidence of "microseismic storms" in different regions is shown in Fig. 17. There is some indication that the disturbances from North America to Europe tend to occur on the same days, but the stations in the other regions seem quite independent of each other and of the European and American groups.

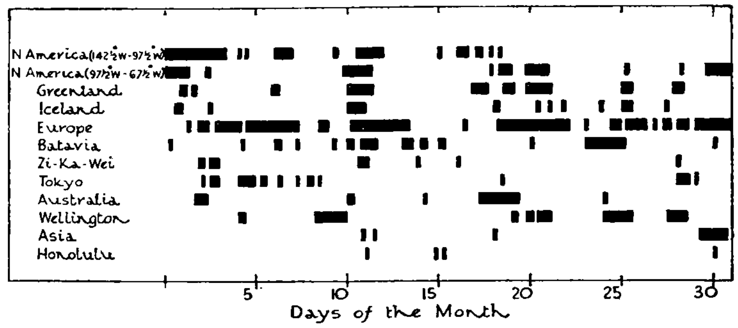

FIG. 17.—DISTRIBUTION OF "MICROSEISMIC STORMS" DURING JANUARY, 1930.

The 23rd was the only day on which relatively large microseisms were not recorded somewhere; they were rare from the 8th to 10th, 15th to 16th, 24th to 25th and on the 27th. The amplitudes at Perth and La Paz were less than double the mean throughout the month. The most notable spells of disturbance, together with the regions affected, are :—

January	1–3 :	North America, Greenland and Iceland.
	4–6 :	North-east to south-west Europe and Japan.
	11–12 :	Europe, Batavia, Honolulu, North America and Greenland.
	20–22 :	Central and eastern Europe, one observatory in North America, Greenland and Iceland.
	30–31 :	Europe, Apia and North America.

§ 8—THE GEOGRAPHICAL DISTRIBUTION OF MICROSEISMS IN EUROPE AND IN NORTH AMERICA

There is a good network of observatories in Europe, but the microseismic distribution cannot be obtained directly from the tabulated amplitudes since, in addition to instrumental uncertainties, these are affected by the variations in the thickness and composition of the sedimentary layer. To overcome this difficulty Gutenberg considers the ratio of individual amplitudes to the mean of the maximum amplitudes in a number of microseismic storms. He terms these the "relative amplitudes," and states that "this method has the advantage that errors in the determination of the magnification of the instrument and the effect of the subsoil are eliminated, but on the other hand a factor influenced by the distance from the source of the motion is lost." The disadvantage arises from the assumption that the mean maximum amplitude should be the same at all stations. From maps of the relative amplitudes in Europe and in North America he finds that the large microseisms are associated with storms near the coasts.

In the present work I have adopted a different method to allow for the properties of the underlying sedimentary material. Since the amplitudes at different stations can only be compared if they refer to uniform conditions, let the "standard amplitude" be defined as the amplitude at the surface for Rayleigh waves in granite with energy equal to that of the microseisms. The "standard amplitudes" for any observatory are equal to the recorded amplitudes divided by a factor* which represents the "sedimentary magnification." The factor indicates the horizontal amplitude which would be registered for microseisms in which the energy is equal

* The variation of factor with period will be neglected; the factors obtained from (6) refer to microseisms of period 2π seconds.

TABLE VIII—OCCASIONS OF AMPLITUDES GREATER THAN

DAY OF

Observatory	1	2	3	4	5	6	7	8	9	10	11	12	13	14
														Hours of
Dyce				1							13,18	1,7,13		
Edinburgh ..											13,18	1		
Durham ..						1					13,18	1,7		
Stonyhurst ..											13,18	1,7		
Bidston ..											7,13,18	1,7		
De Bilt ..						7					7,13,18	1,7,13,18	1,7	
Oxford ..											7,13,18	1,7		
Kew					13						13,18	1,7,13	1	
Uccle											7,13,18	1,7,13	1, 13	1
Parc Saint Maur											7,13,18	1,7,13,18		
Neuchatel ..											7,13,18	1,7,13,18	1,7,13	
Barcelona ..						13,18	1,7,13				13,18			
Ebro							1				18	1,7	1	
Toledo											18	1,7,13,18		
Abisko ..														
Uppsala ..				7,13,18	13,18	1,7,13,18	1				13,18	1		
Lund				7,13	13,18	1,7,13,18	1	1			13,18	1,7		
Copenhagen ..				7,13	13,18	1,7,13,18	18	1,7			7,13,18	1,7,13		
Königsberg ..						1,13								
Hamburg ..						13					7,13,18	1		
Potsdam ..						1,7,13		7			13,18	7,13	13	
Göttingen ..									7, 18		7,13,18	1,7,13	1,7, 18	1,7
Leipzig.. ..											7,13,18			
Eger											17,23	5		
Heidelberg ..											7,13,18	1,7,13;18	1,7,13	
Strasbourg ..					13	1,7					7,13,18	1,7,13,18	7,13	7
Vienna ..			7, 18	7,13	18	7,13,18		7			7,13,18	1,7,13;18	1,7,13	
Munich ..											7,13,18	1,7,13	13	
Zürich		7, 18	1								13,18	1,7,13		7
Chur											13,18	7,13	7, 18	
Zagreb ..											7,13,18	1,7		
Cape Town ..														
Helsingfors ..				1,7, 18	1, 13,18	1,7,13,18					13,18	1,7	1	
Pulkovo ..				7, 18	13,18	1,7,13,18					18			
Kučino.. ..				6										
Batavia ..	7				7		1,7	7		7	1,7, 18	1,7,13		1,7,13
Zi-Ka-Wei ..		18	1, 13,18								13,18	1		18
Perth														
Tokyo			1, 13,18		1,7,13,18	7,13	7	7, 18	1, 13					
Riverview ..		13,18									1,7			
Melbourne ..		13,18	1,7											
Apia											18	13		
Wellington ..					1,7				7,13,18	1,7,13,18				
Honolulu ..												1		
Sitka		18	1								13,18	1,7,13,18		
Victoria ..	1,7,13,18	1,7,13,18	1,7,13,18	1,7								13,18		
Tucson ..					1, 13		1,7,13,18			7	13,18	1,7,13,18		
Florissant ..	1,7, 18										7,13,18	1,7		
Ottawa ..	1,7,13,18	1,7	7								13,18			
Harvard ..	1,7,13									18	1,7,13			
Georgetown ..											18			
La Paz ..														
Ivigtut ..	18	1, 13				18	1				1,7,13,18	1		
Scoresby Sund											7,13,18	1,7		
Reykjavik ..	13,18		13								1,7,13,18			

TWICE THE MEAN FOR THE MONTH. JANUARY, 1930

MONTH

15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Observation																
															7,13,18	
											7,13	7			13	
															1	1
												7				1
															7, 18	1,7,13,18
											7,13,18	1, 18			18	1, 13,18
					13,18	1,7,13,18	1,7,13,18									
						7,13,18	1,7,13,18	1						1		
						1,7,13,18	1,7,13,18									
						7,13,18	1,7,13,18	1							7	
						7,13,18	1, 13,18									
						7,13,18	13,18									
						13,18										
																1,7, 18
																7
						11,17								23	5,11,17,23	5,11
										13,18						
											7, 18					
						7,13,18	13,18									
															13	
									1						7, 18	18
						7, 18					7				1, 13,18	13
													7,13	7,13	7	13
				18	1									13	1	
		13		7,13,18	1,7,13,18	1,7,13,18	1, 13,18									
					18	1,7, 18	1,7,13,18									
					12	0,6,12,18	6,12,18									
1,7	1,7					1			1,7,13,18	1,7,13,18	1					1
		1												1		
				13										1,7,13	1	
			18	1,7,13						1						
7			7,13,18	1,7,13,18	1,7											
				1											7,13,18	1,7,13
					1,7, 18	1, 13,18	1			1,7,13,18	1,7,13		13,18	1,7,13		
18	7															1
			18													
	1	1, 13	7													
		7	1, 18	7												
			18			1,7,13,18					7			7	13,18	1,7,13,18
			18	13,18	18										13,18	1,7,13,18
				7,13,18												1,7,13,18
															13,18	1,7,13,18
		18	1,7,13		18	1,7;13,18	1				1,7,13		18	1,7		
				13,18	1											
				1,7		13	1, 18		18		1,7,13		13			

to that for Rayleigh waves in granite with a surface horizontal amplitude of 1 μ. The factors used are those for reduction of the horizontal amplitudes; the vertical amplitudes, being affected to a lesser extent by the underlying material, would require smaller factors.

For any observatory the factor can be determined from the ratio of the horizontal to the vertical amplitude; it is unity when $A_H/A_Z = 0{\cdot}7$, and the data of (6) (Table V) show that it increases to $2\frac{1}{4}$ as A_H/A_Z increases to $1{\cdot}3$, the relation being practically linear and independent of the material in the superficial layer. In addition we infer that the factor is unity at observatories on the Archæan rocks which are nearest to the sub-continental granitic layer and for which roughly speaking the elastic constants of granite are appropriate, even if the ratio A_H/A_Z is not known.

The factor has been determined for each observatory in Europe, Greenland and in North America. It is unity at Dyce, Toledo, Abisko, Uppsala, Helsingfors, Pasadena, Georgetown, Ivigtut and Scoresby Sund, $1\frac{1}{2}$ at Kew, Pulkovo and Kučino, and $1\frac{3}{4}$ at Copenhagen. The ratios A_H/A_Z for de Bilt and Strasbourg are outside the range investigated in (6) and provisional factors of about $4\frac{1}{2}$ are obtained by extrapolation. At Uccle and Hamburg the ratios A_H/A_Z are larger than would be appropriate for the geological formations around the observatories, the values of A_Z being probably underestimated owing to the short free period of the seismographs. For these two stations and for the remaining observatories in Europe, provisional factors were assumed which would apply to the geological structure in the vicinity.* To reduce the effects of friction and of errors in the magnification the mean amplitudes of January 11 to 12, divided by these factors were mapped, and the provisional factors were revised to smooth out the irregularities between neighbouring observatories. The factors for observatories in North America cannot be determined by this method owing to the sparse distribution of the stations, and the values for European observatories on similar geological formations have been adopted.

The data for Greenland and Iceland are very important. Fortunately the amplitudes at Ivigtut and Scoresby Sund, being obtained on gneiss, need no reduction, but a factor is required for Reykjavik on tertiary basalt. An error in the factor at Reykjavik would distort the distribution around Iceland, but would not affect the other regions and the inclusion of a less reliable factor appeared preferable to rejecting this valuable station. The same factor as for Edinburgh (on Devonian lava) was taken as it gives a fairly smooth distribution of the microseisms from Greenland to north-west Europe.

The factors for the various observatories are as follows :—

Factor	*Observatories*
1	Dyce, Uccle, Toledo, Abisko, Uppsala, Göttingen, Leipzig, Chur, Helsingfors, Pasadena, Florissant, Ottawa, Harvard, Georgetown, Ivigtut, Scoresby Sund.
$1\frac{1}{4}$	Durham, Stonyhurst, Heidelberg.
$1\frac{1}{2}$	Kew, Neuchatel, Munich, Zürich, Pulkovo, Kučino, Tucson, Chicago.
$1\frac{3}{4}$	Edinburgh, Lund, Copenhagen, Victoria, Reykjavik.
2	Bidston, Oxford, Parc Saint Maur, Barcelona, Ebro, Eger, Potsdam, Vienna, Zagreb, Sitka.
3	Königsberg, Hamburg, Toronto.
4	Strasbourg
$4\frac{1}{2}$	De Bilt.

The "standard amplitudes" of the microseisms in North America at 7h. on the 3rd, 6th, 12th, 21st and 30th, are given in Table IX. With the amplitudes so

* It is very difficult to estimate the effects upon the microseisms of the various formations, but probably they are not serious unless the areas are large compared with the wave length, or unless the thickness exceeds 0·1 Km. Information concerning the structure around the observatories was supplied with the tabulations of microseisms and in many cases was very comprehensive.

PRESSURE, WIND AND SEA DISTURBANCE.

HORIZONTAL "STANDARD AMPLITUDES" OF THE MICROSEISMS

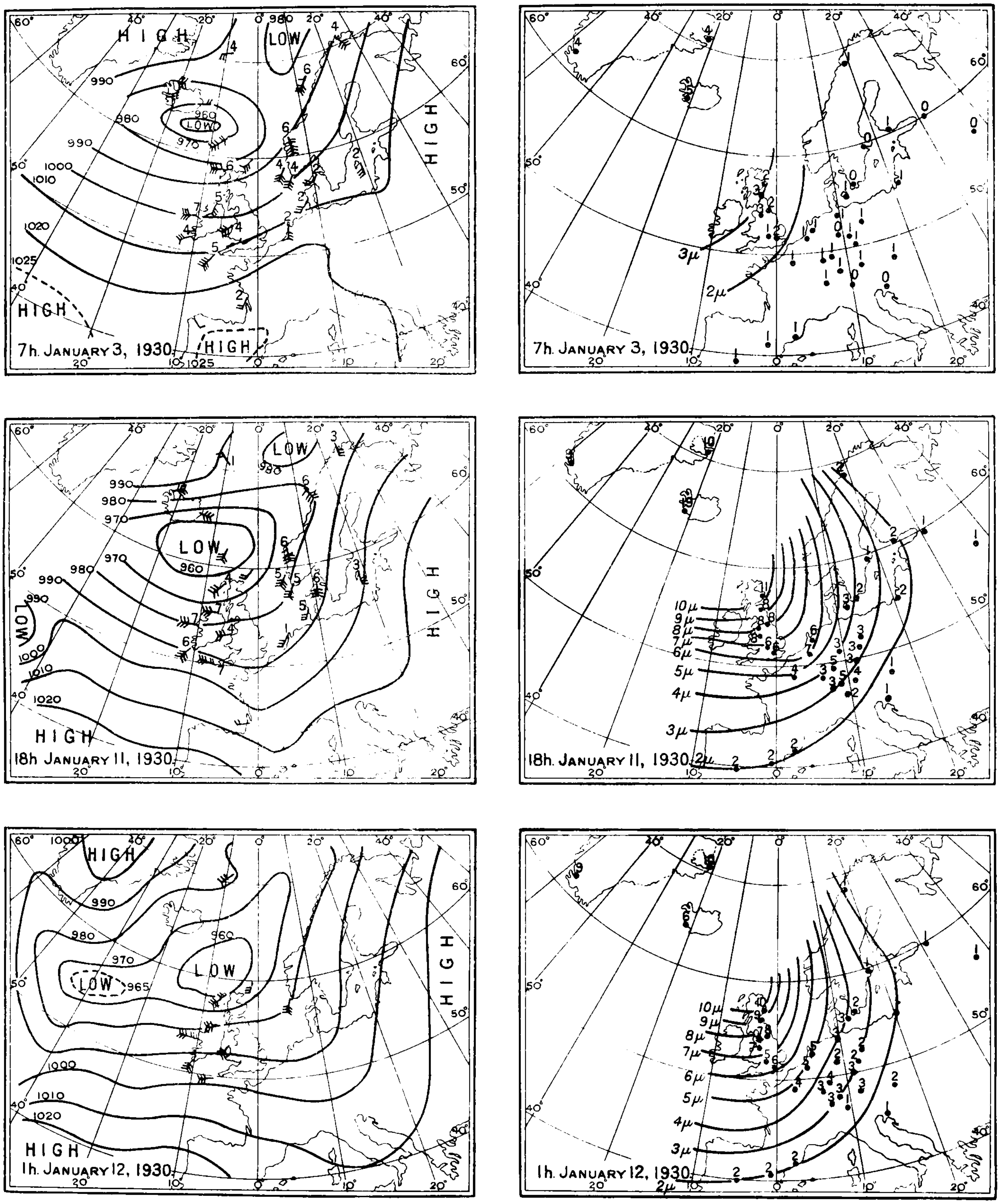

Fig. 18. SYNOPTIC CHARTS AND DISTRIBUTION OF MICROSEISMS. JANUARY 1930.

PRESSURE, WIND AND SEA DISTURBANCE.

HORIZONTAL "STANDARD AMPLITUDES" OF THE MICROSEISMS.

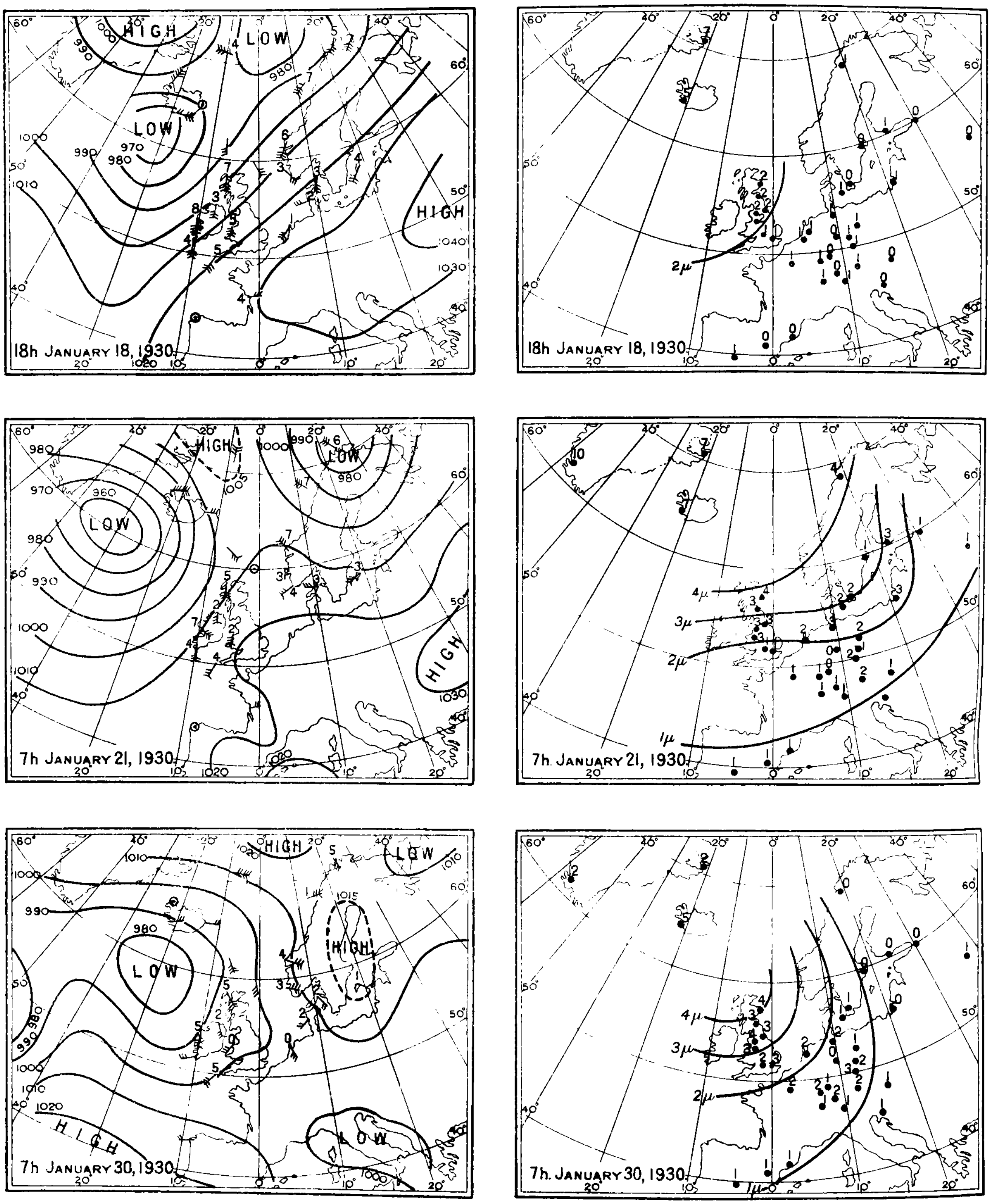

Fig. 19. SYNOPTIC CHARTS AND DISTRIBUTION OF MICROSEISMS. JANUARY 1930.

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much less than those in north-west Europe, and with so few stations, only the main features of the distribution are brought out in this table. For the hours included the amplitudes near the Pacific and Atlantic coasts were greater than those inland ; this result is in agreement with that obtained by Gutenberg.

TABLE IX—NORTH AMERICA. HORIZONTAL "STANDARD AMPLITUDES" OF THE MICROSEISMS ON SPECIFIED DAYS OF JANUARY, 1930

Observatory	3rd, 7h.	6th, 7h.	12th, 7h.	21st, 7h.	30th, 7h.
	μ	μ	μ	μ	μ
Sitka	0·7	—	0·9	0·4	—
Victoria	1·7	0·0	0·9	0·7	0·9
Pasadena	0·7	0·5	0·7	0·3	0·3
Tucson	—	0·3	0·6	0·2	0·0
Chicago	0·5	0·0	0·5	0·5	0·0
Florissant	0·4	0·2	0·5	0·6	0·4
Ottawa	0·8	0·2	0·4	0·6	0·4
Toronto	—	0·0	—	0·9	—
Harvard*	1	1	1	<1	1
Georgetown†	0·8	0·6	1·1	1·1	1·1

* Tabulations only available to nearest 0.25 mm. or 1 μ.
† No horizontal seismograph ; A_H taken as 0.7 A_Z.

The geographical distributions of the microseisms from Greenland to Europe for a number of occasions during January, 1930, have been examined ; the occasions selected were 3rd, 7h. ; 6th, 7h. and 18h. ; 18th, 18h. ; 21st, 7h. ; 30th, 7h., and each of the four hours tabulated on the 11th and 12th. The synoptic charts and the distributions of the horizontal "standard amplitudes" for six of these occasions appear in Figs. 18 and 19. The microseismic distributions have been drawn to be continuous over Europe and the British Isles, Greenland and Iceland being regarded as independent areas since the intervening seas are of considerable depth. Irregularities in the distributions of the microseisms are to be expected and at a few stations (notably at Uppsala and at Göttingen) the amplitudes are apparently underestimated owing to friction in the seismographs. The maps show clearly how the disturbance diminishes with increasing distance from the region of maximum amplitudes. For the occasions studied the "standard amplitudes" were smaller on the continent of Europe than near the western seaboard ; they were generally much larger in Iceland and in the British Isles than in the regions east of the North Sea. Comparisons of the weather maps and the distributions of the microseisms are given in § 11.

§ 9—THEORIES CONCERNING THE ORIGIN OF MICROSEISMS

The widespread belief that microseisms are connected with atmospheric disturbances was mentioned in earlier sections. The close agreement between the periods of the microseisms and of sea waves has been accepted for many years as evidence that the phenomena are related, and the theories which have been propounded to explain the origin of microseisms have generally endeavoured to show how they could be generated from the waves caused by depressions over adjacent seas. The following are the more important of the theories.

In the opinion of the Japanese seismologists microseisms at Tokyo are free oscillations of the subsoil in the vicinity, occurring when the period of the applied disturbance agrees with a natural period of oscillation of the ground. The hypothesis has been developed by K. Wadati (16), by T. Matuzawa (17) and others. Wadati agrees with Gutenberg's hypothesis (given below) that the original disturbance is caused by the impact of sea waves on the coast. Matuzawa has made extensive comparisons of the microseisms in Tokyo and the distribution of atmospheric pressure; he shows that the microseisms are smaller when a deep depression over the land raises high seas in Tokyo Bay than those observed when a deep depression is advancing far off the coast, and he concludes that the direct effect of the sea waves cannot be the primary cause of the microseisms.

E. Gherzi (18, 19) and S. K. Banerji (20) have also noted occasions on which large microseisms were recorded when storms approached the coasts. The former has suggested that the microseismic oscillations are due to variations of air pressure over the sea, the latter that the waves raised by storms over the oceans cause changes of pressure on the sea bed, thus setting up forced oscillations which are propagated as microseisms when they reach the coast. Gutenberg has pointed out an error in Banerji's calculation of the disturbance at the bottom of the sea due to the waves, and shows that in deep water the changes in pressure on the sea bed would be very small. It is doubtful whether Banerji's treatment is appropriate for ocean waves, since the analysis is based upon the hydrodynamical theory of irrotational gravity waves on the surface of a perfect fluid. A mathematical investigation of the motion of the sea bed and of the superposed water due to atmospheric disturbances has been given by K. Sezawa and G. Nishimura (21). These authors conclude that "microseisms . . . are chiefly due to long water waves including breakers at the coast advancing near the observing station."

From study of the microseisms recorded at Athens, N. Critikos (22) suggests that the oscillations are mainly due to the action of strong winds on the uneven surface of the earth setting up wave motion analogous to the sea waves; he finds some evidence, however, in favour of other causes of less importance such as the variations in pressure on the sea bed and the impact of waves on the coasts.

J. Lacoste and W. Kohlbach are other investigators who hold the opinion that the microseisms are connected with depressions over adjacent seas. The former has studied the microseisms recorded at Strasbourg from 1920 to 1929 in relation to the travel of depressions from the Atlantic towards the western coasts of Europe, and the latter has examined (23) the meteorological conditions which accompanied a large number of "microseismic storms." In the correspondence relating to the present investigation similar views have been expressed by the directors of the observatories at Perth and Victoria.

O. Klotz has compared the microseisms at Ottawa with the weather maps (24), and finds that the largest microseisms are generally recorded when depressions are situated near the Gulf of Saint Lawrence, the amplitudes depending chiefly on the barometric gradient.

The most popular hypothesis still seems to be that developed by Wiechert, Linke and Gutenberg, which attributes the microseisms to the impact of surf on steep rocky coasts. Gutenberg believes that the microseisms are best developed in Europe and in North America when depressions are situated off the coasts, and that storms over the continents do not generate microseisms. He claims that large sea disturbances off the coast of Norway may generate microseisms which extend over the whole of Europe and the western half of Asia, and that storms off the coasts of Newfoundland and Canada cause large microseisms over the whole of North America. A steep rocky coast is postulated in this hypothesis to ensure that the surf breaks violently and transfers the energy of the waves to the ground with a minimum amount of friction. Gutenberg has considered the order of magnitude of the quantities involved in this process and concludes that the energy transferred to the coast by surf is large enough to cause the microseisms. No exact explanation of how the breaking of the surf sets the ground in oscillation is given, but presumably Gutenberg envisages each breaker as a tiny earthquake generating surface waves. A difficulty at once confronts such an hypothesis, for the impacts of the waves would not occur simultaneously along the whole coastline affected, and consequently

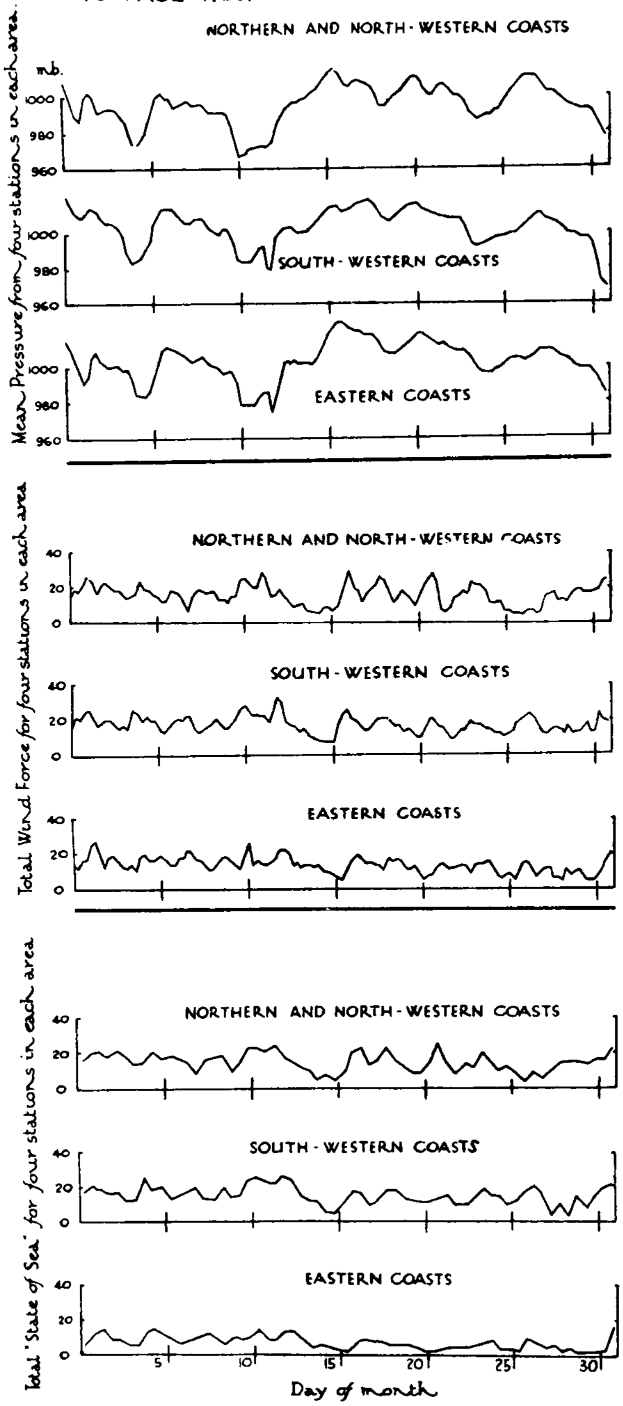

Fig 20. PRESSURE, WIND FORCE AND STATE OF SEA AT COASTAL STATIONS IN THE BRITISH ISLES JANUARY 1930.

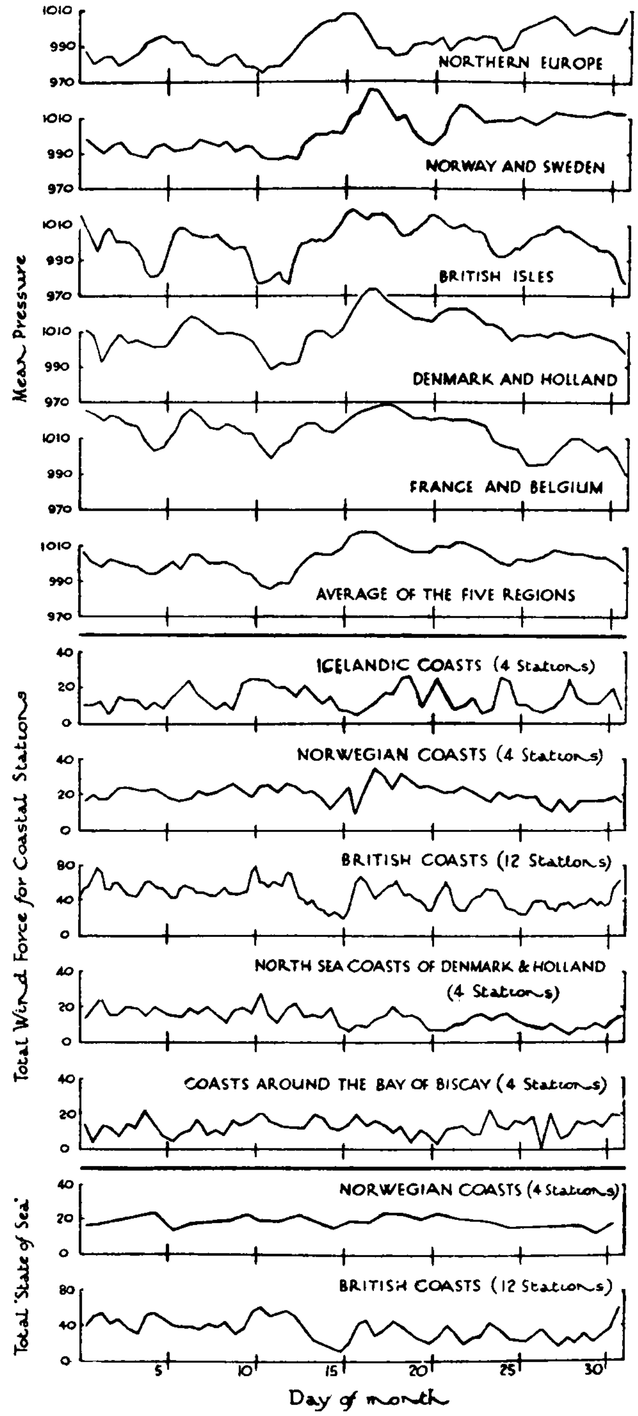

Fig. 21 PRESSURE, WIND FORCE AND STATE OF SEA IN NORTHERN AND WESTERN EUROPE JANUARY 1930

the agreement between the periods of the microseisms and of the sea waves is not explained.

§ 10—THE CONNEXION BETWEEN MICROSEISMS AND METEOROLOGICAL CONDITIONS

Since all the current theories presuppose that the microseisms are connected with the weather, comparisons must be made between the microseisms in Europe during January, 1930, and the meteorological conditions. Data of pressure, wind speed and sea disturbance,* extracted from the *Daily Weather Report*, are plotted in Figs. 20 and 21 ; the former represents conditions observed at coastal stations in the British Isles, the latter, conditions in various localities of northern and western Europe. The values of Fig. 20 have been obtained from four stations in each of the following regions :—

(i) Northern and north-western coasts. (Wick, Stornoway, Malin Head, Blacksod Point.)

(ii) South-western coasts. (Valentia, Holyhead, Pembroke, Scilly.)

(iii) Eastern coasts. (Edinburgh, Tynemouth, Spurn Head, Gorleston.)

The pressure values are means of the observations at the four stations in each area ; wind force and state of sea are represented as the total Beaufort force and sea disturbance respectively at these stations. Values of pressure and wind are available at all four hours for which the microseisms have been measured, but sea disturbance is only recorded twice daily (7h. and 18h.). For the British Isles in Fig. 21, the pressures are the means, and wind and sea disturbance are the aggregates of observations at the 12 coastal stations. The pressure curves for other regions have been constructed from the means at 7h. and 18h. at coastal and inland stations, the regions being selected according to the classification of the International Section of the *Daily Weather Report*. The changes in wind on Icelandic and continental coasts, and in sea disturbance on the Norwegian coast, are taken from the aggregates of observations at four coastal stations in each area ; the regions and stations are :—

(i) Icelandic coasts. Isafjord, Reykjavik, Vestmanno, Seydisfjord.

(ii) Norwegian coasts. Ingöy, Röst, Kinn, Utsire.

(iii) North Sea coasts of Denmark and Holland. The Scaw, Blaavands Huk, Helder, Flushing.

(iv) Coasts around the Bay of Biscay. Brest, Rochefort, Bayonne, Corunna.

Wind values are available for 7h. and 18h., sea disturbance only for 7h.

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* The sea disturbance figures for January 1930, refer to the " Old " International Code which was superseded by the " New " Code from March 1930. The two codes are :—

Figure	Old code		New code
0	No swell	Calm or slight sea	Calm
1	Moderate swell		Smooth
2	Heavy swell		Slight
3	No swell	Moderate sea	Moderate
4	Moderate swell		Rough
5	Heavy swell		Very rough
6	A rather rough sea		High
7	Rough sea		Very high
8	Very rough sea		Precipitous
9	Mountainous sea		Confused

The old code allowed for reporting both the state of sea and character of swell, and the new one does not. Probably in the case of an indirect association between sea disturbance and microseismic activity the discontinuity would be of little importance. It might be supposed, however, that earth waves would be more likely to be generated by the regular and slow swell rather than by the irregular sea disturbance.

Mere inspection of these curves and of those showing the variations in amplitude and period of the microseisms (Figs. 4–7), fails to reveal any obvious connexion between the microseisms and the pressure, wind or state of the sea in the regions considered. The most conspicuous features in the amplitude curves for western Europe are the maxima of the 11th to 12th, when the values were three or four times as great as the means for the month. At this time the average pressure for the five regions was the lowest during the month, but on other days the variations in amplitude do not resemble those in the average pressure. On the 11th and 12th the wind and sea disturbance round Britain were large following a sharp rise on the 10th, but the changes around the Norwegian coast were smaller. The absence at this time of any prominent maximum in the sea disturbance off Norway is notable, for this is the locality believed by Gutenberg to be the most favourable for the generation of microseisms.

The German seismologists have found large correlation coefficients between the microseismic amplitudes and B^2, a function of the sea disturbance off Norway obtained from the formula $B^2 = (n^2 + 2m^2 + 3s^2) / 6$, n, m and s being the sea disturbance at Bodö (north), Christiansund (central) and Skudesnes (south) ; the factors 1, 2 and 3 are introduced to allow for the differences between the distances from Germany. These stations are not included in the British *Daily Weather Report*, but values of B^2 have been computed from the above formula using the stations Röst (n), Kinn (m) and Utsire (s). The daily values at 7h. of B^2 and of the horizontal amplitudes at Lund, Königsberg, Hamburg and Göttingen are given in Table X. For the whole month the correlation coefficient between B^2 and the microseismic amplitude is

$+ 0{\cdot}44 \pm 0{\cdot}10$ (p.e.) for Lund,

$+ 0{\cdot}66 \pm 0{\cdot}07$ (p.e.) for Königsberg,

$+ 0{\cdot}57 \pm 0{\cdot}08$ (p.e.) for Hamburg,

and $+ 0{\cdot}18 \pm 0{\cdot}11$ (p.e.) for Göttingen.

The coefficient for Göttingen is much less than those for the stations nearer to the coasts ; this difference cannot be due to the small amplitudes at Göttingen for the correlation coefficients depend chiefly upon the large deviations from the means and are only slightly affected by the minor fluctuations.

In computing the correlation between sea disturbance and the amplitudes at Königsberg it was noticed that the connexion was much closer from the 19th to 31st than during the earlier part of the month. For the former interval the coefficient is found to be $+0{\cdot}92 \pm 0{\cdot}03$ (p.e.). This high coefficient is due to the values of B^2 and of the amplitudes being greater than the average from the 19th to 23rd and less than the average subsequently, so it really depends upon only one event. For one observation (7h.) daily throughout the month the correlation between the amplitude (A_z) and pressure at Kew is $-0{\cdot}39 \pm 0{\cdot}10$ (p.e.) which is about as large as that between B^2 and the amplitudes at Lund. The correlation coefficients between the pressure at Kew and amplitudes at Königsberg are $+0{\cdot}41 \pm 0{\cdot}10$ (p.e.) for the whole month, and $+0{\cdot}84 \pm 0{\cdot}05$ (p.e.) for the last thirteen days. During January 1930, the correlation between the microseismic amplitudes at Hamburg and sea disturbance was less than that obtained by E. Tams for the interval January 20 to February 10, 1932, (25) when there were eight corresponding maxima in the amplitudes and in the sea disturbance. The coefficients which have been obtained support the conclusion that the microseisms are connected with storms over adjacent seas, but do not prove that they are caused by the action of the sea waves. Obviously much longer intervals ought to be studied before the correlation between the microseisms and meteorological agencies can be accepted.

Figs. 18–19 show that when the microseisms in Europe were large, depressions were situated north-west of the British Isles. Over the British Isles and the

TABLE X—VALUES AT 7h. OF B^2 AND THE HORIZONTAL AMPLITUDES OF MICROSEISMS AT LUND, KÖNIGSBERG, HAMBURG AND GÖTTINGEN. JANUARY, 1930

Day	B^2	Amplitude of microseisms (greater horizontal component)			
		Lund	Königsberg	Hamburg	Göttingen
		μ	μ	μ	μ
1	18	—	3·0	2·4	0·3
2	19	0·5	3·1	4·9	0·3
3	26	0·5	2·1	3·9	0·3
4	35	3·7	5·4	6·6	0·3
5	31	1·5	3·8	5·6	0·3
6	23	4·8	5·9	7·7	0·3
7	18	1·5	4·1	3·6	0·6
8	21	1·2	4·0	3·5	0·3
9	24	0·7	3·8	4·7	0·9
10	24	0·7	4·7	3·7	0·6
11	29	1·2	3·4	6·5	1·0
12	26	2·8	4·0	7·0	1·5
13	29	1·4	3·6	6·1	0·9
14	24	1·5	3·0	4·4	0·6
15	16	1·7	3·8	3·2	0·6
16	19	0·2	3·3	3·5	0·3
17	19	0·2	5·1	4·1	0·3
18	28	0·2	3·1	3·5	0·3
19	28	0·7	4·6	3·5	0·0
20	25	1·4	5·4	7·6	0·3
21	29	3·1	7·8	8·1	0·3
22	27	2·6	6·0	7·4	0·3
23	24	1·7	4·9	4·4	0·3
24	19	0·2	2·1	4·8	0·3
25	13	0·2	2·1	2·8	0·3
26	15	0·7	2·0	3·6	0·3
27	15	0·2	2·5	3·9	0·6
28	15	0·2	1·1	3·5	0·3
29	13	0·7	0·9	3·5	0·0
30	10	1·6	1·0	5·6	0·3
31	14	0·7	0·5	3·9	0·6
Mean	22	1·3	3·6	4·8	0·4

continent the distribution of the microseisms for each occasion closely resembles that of atmospheric pressure, the largest amplitudes being recorded in the regions of lowest pressure. The inference is apparently that the large microseisms were associated with these storms, but there is nothing to show by what process the microseisms were generated. Throughout the " microseismic storm " of the 11th to 12th a deep depression was situated between Scotland and Iceland ; another depression, which was first shown north-west of the Azores on the 11th at 18h. crossed the British Isles on the 12th. Early on the 11th the microseisms were largest near Iceland but from 7h. there was a large increase in the amplitudes in Great Britain and on the continent, the maxima occurring from the 11th, 13h. to the 12th, 1h.; between the 11th, 18h. and 12th, 1h. the amplitudes at Reykjavik diminished greatly, but the subsequent cessation of disturbance in other regions was more gradual. As far as can be seen there was no change in the pressure distribution with which the rapid fall in the Reykjavik amplitudes could be connected.

The maps for 7h. on the 3rd and 18h. on the 18th have been included as examples of the occurrence of storms north-west of the British Isles which were not associated with abnormally large microseisms. The synoptic chart for 7h. on the 3rd closely resembles that for 18h. on the 11th, each showing a deep depression between

Scotland and Iceland and a secondary off northern Norway. On both days there were strong winds and rough seas round north-west Europe, but there is a striking contrast between the microseisms, the amplitudes on the 3rd being only about half or one third of those on the 11th. The maps for 18h. on the 18th and for 7h. on the 21st are of similar type, with stormy conditions round north-west Europe; again the microseisms are very different on the two days. It is evident that although large microseisms in Europe during January, 1930, only occurred when depressions were situated over the eastern Atlantic, the converse was not always the case, and we conclude that the microseisms cannot be caused solely by storms near the coasts.

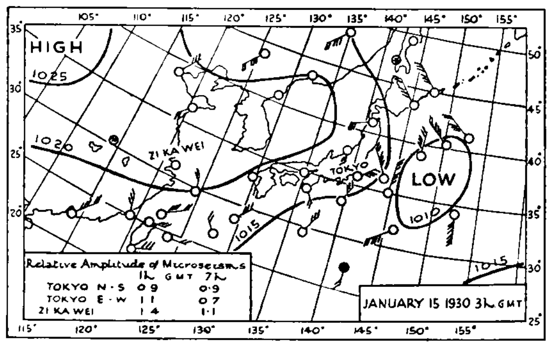

FIG. 22.—SYNOPTIC CHART FOR EASTERN CHINA AND JAPAN. JANUARY 15, 1930.

This conclusion is supported from comparisons of the microseismic distributions and weather maps in other regions. Examples are given in Figs. 22 and 23. The former shows a shallow depression off the eastern coasts of Japan, with much stronger winds near the Pacific coast than over the China Sea, at a time when the microseisms (relative to the monthly means) were larger at Zi-Ka-Wei than at Tokyo. Conditions round the Atlantic coasts of North America, on two days of large microseisms, appear in Fig. 23. The situation on January 29 was examined by Gutenberg,(12) who believes that large microseisms in North America are due to waves breaking against the steep rocky coasts of Newfoundland and Canada when depressions are situated near the mouth of the St. Lawrence. However it will be seen that on the 12th the microseisms were larger than on the 29th, but on the former date an anticyclone

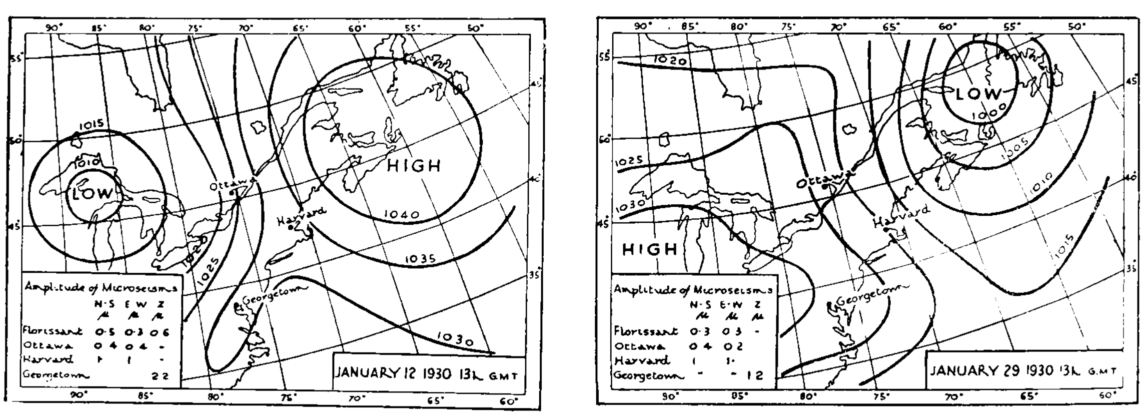

FIG. 23.—CONTRASTING PRESSURE DISTRIBUTIONS ON DAYS OF LARGE MICROSEISMS IN EASTERN NORTH AMERICA, JANUARY, 1930, AS COMPUTED FROM GUTENBERG'S TABULATIONS.

was located off the eastern coasts and a shallow depression over the Great Lakes, showing that the large microseisms are not invariably associated with storms on the Atlantic seaboard.

The general conclusion from this discussion of the relation between weather and microseisms in the month under review, January, 1930, is that microseisms are associated with deep depressions over the oceans, but not particularly with depressions causing waves on adjacent coasts.

Seismologists have been inclined to fight shy of the idea that sea waves far from land can generate microseismic waves which reach our observatories. There are two theoretical objections, one being that the disturbance in water falls off very rapidly with increasing depth, and the other that the length of a sea wave is very small compared with the length of a seismic wave. F. J. W. Whipple has examined (15) the validity of these objections, and gives a new hypothesis which is set out in the following paragraphs from his paper.

" Thus it seems that sea waves in deep water are effective and that the mathematician's objection that the waves cannot affect the sea bottom is ill-founded.

" When there is disagreement between physical facts and a mathematical theory one expects to find that the physical circumstances have been oversimplified in the specification of the mathematical problem. In the present case the mathematician considers an infinite train of regular waves and assumes that his deductions from the theory of the infinite train will apply without serious modification to actual waves. Moreover he regards the water as incompressible. It is not difficult to incorporate in the theory of the infinite trains an allowance for the compressibility of the water. The correction is of little importance, the law by which the movement falls off exponentially with increasing depth is hardly modified. The case must be different however with actual water waves. As the water waves progress and change their form there must be disturbances propagated through the water as waves of compression travelling with the velocity of sound. In general these compressional waves will not obey the exponential law. The compressional waves which reach the bottom will generate microseismic waves in the ground. Thus it is suggested that we may look to the upper surface of the sea rather than to the sea bottom as the source of the microseisms recorded by our instruments."

§ 11—SUMMARY

A survey of the microseisms recorded during January 1930 has been made from tabulations of the amplitude and period at 57 observatories.

At observatories equipped with two horizontal seismographs, the mean amplitudes of the microseisms recorded on the two components are approximately equal, but discrepancies may occur if the surrounding geological formations are not symmetrical. The ratio between the horizontal and vertical mean amplitudes varies from 0·6 to 3, the value at any observatory depending upon the underlying structure.

In some regions there are regular diurnal variations in the microseismic disturbance. The variations in the amplitude on days of large and of small microseisms are of similar type, and follow local time with minima in the night and maxima by day. In other localities there is no evidence of systematic variations. The changes are apparently of local origin.

A new method is developed whereby the amplitudes at observatories on different geological formations are rendered comparable, and from which the geographical distribution of the microseisms can be determined. The distributions in Europe (where there is a good network of observatories) have been examined for a number of occasions ; the microseisms were usually much larger in Iceland and the British Isles than in the regions east of the North Sea.

The occurrences of large microseisms in several regions, especially Europe, have been examined in relation to the associated meteorological conditions. In Europe the " microseismic storms " are generally associated with depressions off the coasts, but some deep depressions are not accompanied by large microseisms.

The current theories concerning the origin of microseisms are set out, but no theory furnishes a satisfactory explanation of the phenomena which were recorded during January 1930.

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I wish to express my thanks to Dr. F. J. W. Whipple, Superintendent of Kew Observatory, for his continued interest and advice throughout these investigations. I must also thank the directors and seismologists of the observatories who have been so kind as to lend their seismograms or to supply tabulations of the microseisms.

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APPENDIX. TABLE II.—MICROSEISMS DURING JANUARY 1930.

Locality	Observatory	Seismograph: Type	Seismograph: Component	Seismograph: Free period	Mean amplitude: 1h	7h	13h	18h	Mean	Mean period: 1h	7h	13h	18h	Mean	Maximum amplitude	Time of maximum amplitude: d.	h.
				sec.	μ	μ	μ	μ	μ	sec.	sec.	sec.	sec.	sec.	μ	d.	h.
7½° W. to 7½° E. Zone 0.	Dyce ..	M.S.	N-S.	12	2·8	2·8	3·0	2·9	2·9	6·4	6·4	6·4	6·4	6·4	10·8	11	18
	Edinburgh	M.S.	E-W.	12	5·7	5·2	5·5	5·3	5·4	6·5	6·3	6·4	6·5	6·4	16·6	12	1
	Durham ..	M.S.	N-S.	12	3·4	3·2	3·4	3·4	3·3	6·1	6·1	6·1	6·1	6·1	10·7	11	13
	Stonyhurst	M.S.	E-W.	12	3·5	3·8	3·9	3·7	3·7	6·3	6·3	6·2	6·4	6·3	11·2	11	13
	Bidston ..	M.S.	N-S.	12	4·6	4·5	4·5	4·6	4·6	6·4	6·1	6·3	6·4	6·3	16·0	11	18
	De Bilt ..	G.	N-S.	24·2	5·9	6·2	5·7	5·9	5·9	6·5	6·4	6·5	6·5	6·5	19·7	11	18
	"	G.	E-W.	25·1	7·3	7·6	7·7	7·5	7·5	6·3	6·3	6·5	6·6	6·4	30·0	11	13
	"	G.	Z.	12	2·8	2·6	3·0	3·0	2·9	6·4	6·5	6·7	6·6	6·6	12·5	11	13
	Oxford ..	M.S.	N-S.	12	(3·4)	(3·7)	(3·6)	(3·6)	(3·6)	6·5	6·6	6·5	6·6	6·5	(11·9)	11	13
	"	M.S.	E-W.	12	2·8	3·0	2·8	2·8	2·9	6·5	6·4	6·6	6·4	6·5	9·7	12	1
	Kew ..	G.	N-S.	25·5	2·2	2·3	2·3	2·3	2·3	6·7	6·7	6·6	6·8	6·7	7·2	12	1
	"	G.	E-W.	24·7	2·5	2·4	2·4	2·6	2·5	6·7	6·7	7·0	6·8	6·8	9·4	{11 12	18 1
	"	G.	Z.	12·9	2·6	2·6	2·8	2·7	2·7	6·7	6·7	6·8	6·8	6·7	10·2	12	1
	Uccle* ..	G.	N-S.	24·5	1·5	1·6	1·8	1·6	1·6	6·3	6·5	6·4	6·6	6·5	5·1	12	1
	"	G.	E-W.	24·5	1·3	1·3	1·3	1·4	1·3	6·5	6·5	6·4	6·6	6·5	7·3	11	18
	"	W.	Z.	4·8	0·6	0·9	0·9	0·7	0·8	5·6	5·6	5·6	5·2	5·5	4·2	11	18
	Parc Saint Maur	W.	N-S.	11·5	2·3	3·1	3·0	3·5	3·0	5·8	5·7	5·9	6·1	5·9	12·5	11	13
	"	W.	E-W.	11·6	2·1	2·9	2·9	2·9	2·7	5·9	5·9	5·8	6·0	5·9	9·1	12	1
	Neuchatel	Q.P.	N-S.	2·8	1·2	1·2	1·3	1·3	1·3	5·6	5·6	5·7	5·7	5·6	4·9	11	18
	"	Q.P.	E-W.	2·8	1·2	1·2	1·2	1·2	1·2	5·6	5·7	5·6	5·6	5·6	5·1	11	13
	Barcelona†	M.	N-S.	9·7	(1·7)	(1·7)	(2·1)	(1·8)	(1·8)	6·0	6·3	5·9	6·2	6·1	(4·8)	11	13
	Ebro ..	M.	N-S.	14·8	1·5	1·5	1·5	1·6	1·5	5·2	5·2	5·2	5·3	5·2	5·0	12	7
	Toledo ..	W.	NE-SW.	11·5	0·7	0·7	0·8	0·8	0·7	7·0	7·0	7·5	7·4	7·2	2·4	26	13
	"	W.	NW-SE.	12·5	0·9	0·8	0·9	0·9	0·9	7·3	7·3	7·6	7·2	7·4	2·3	27	1
7½° E. to 22½° E. Zone 1.	Abisko ..	G.	N-S.	11·8	1·1	1·1	1·1	1·1	1·1	5·3	5·1	5·1	5·2	5·2	5·3	{21 21	13 18
	"	G.	E-W.	11·9	0·9	0·9	1·0	1·0	1·0	5·3	5·3	5·3	5·3	5·3	4·8	21	13
	"	G.	Z.	11·6	1·4	1·5	1·5	1·6	1·5	5·3	5·2	5·3	5·3	5·3	7·1	{21 21	13 18
	Uppsala ..	W.	N-S.	8·4	0·26	0·21	0·23	0·26	0·25	5·4	5·3	5·4	5·5	5·4	1·3	21	18
	"	W.	E-W.	8·8	0·22	0·20	0·23	0·23	0·22	5·4	5·3	5·3	5·4	5·3	1·0	21	18
	Lund ..	W.	NE-SW.	11·8	0·8	0·7	0·9	0·8	0·8	5·5	5·7	5·8	5·8	5·7	2·9	6	13
	"	W.	NW-SE.	12·0	1·1	1·3	1·3	1·1	1·2	5·3	5·5	5·7	5·6	5·5	5·1	21	13
	Copenhagen	G.	N-S.	12·6	1·4	1·4	1·5	1·5	1·4	5·9	5·9	6·0	6·0	5·9	5·2	12	1
	"	G.	Z.	8	1·3	1·3	1·3	1·4	1·3	5·9	5·7	6·0	5·9	5·9	3·4	12	1
	"	M.S.	N-S.	12	1·7	1·6	1·7	1·8	1·7	6·0	6·0	6·0	6·1	6·0	5·8	12	1
	"	M.S.	E-W.	12	1·7	1·7	1·8	1·8	1·7	5·9	5·9	5·9	6·0	5·9	4·2	11	18
	"	W.	N-S.	9·6	0·7	0·7	0·8	0·7	0·7	5·7	5·7	5·6	5·6	5·6	2·2	6	18
	"	W.	E-W.	9·6	0·9	0·9	0·8	0·9	0·9	5·6	5·6	5·6	5·6	5·6	2·7	{6 6	13 18
	"	W.	Z.	5·6	0·7	0·6	0·6	0·7	0·7	5·5	5·5	5·5	5·6	5·5	2·7	6	1
	Königsberg	W.	N-S.	9·1	3·5	3·3	3·8	3·9	3·6	5·3	5·3	5·0	5·1	5·2	10·8	21	13
	"	W.	E-W.	8·8	3·4	3·3	3·8	3·7	3·6	5·1	5·1	5·1	5·2	5·1	9·8	22	13
	Hamburg ..	W.	N-S.	9·2	3·6	4·5	4·6	4·4	4·3	6·3	6·2	6·3	6·4	6·3	13·0	11	18
	"	W.	E-W.	9·9	3·5	4·1	4·6	4·3	4·1	6·2	6·4	6·4	6·4	6·3	12·3	11	18
	"	W.	Z.	6·0	0·8	1·4	1·3	1·3	1·2	5·6	5·7	5·6	5·6	5·6	2·6	11	13
	Potsdam ..	W.	N-S.	10·0	1·8	2·3	2·6	2·5	2·3	6·4	6·5	7·1	6·5	6·6	7·5	11	13
	"	W.	E-W.	6·0	0·6	0·9	0·9	0·6	0·8	5·0	5·2	5·5	5·1	5·1	2·4	6	13
	Göttingen	W.	N-S.	10·7	0·32	0·34	0·30	0·38	0·34	7·2	6·8	7·2	7·1	7·1	1·5	11	18
	"	W.	E-W.	12·7	0·39	0·38	0·38	0·43	0·40	7·1	7·3	7·4	7·3	7·3	2·9	11	18
	"	W.	Z.	4·0	0·8	0·8	0·7	0·8	0·8	7·3	7·5	7·4	7·1	7·3	2·5	{11 12	18 1
	Leipzig ..	W.	N-S.	10·1	1·0	1·1	1·2	1·1	1·1	7·0	7·2	7·2	7·1	7·1	3·3	11	18
	"	W.	E-W.	9·7	1·1	1·4	1·2	0·9	1·1	7·1	7·2	7·1	7·1	7·1	3·1	11	13

* Means of 1st to 20th only.
† Amplitudes doubtful owing to low magnification of seismograph.

TABLE II—*continued.*

Locality	Observatory	Seismograph			Mean amplitude					Mean period.					Maximum amplitude	Time of maximum amplitude
		Type	Component	Free period	1h	7h	13h	18h	Mean	1h	7h	13h	18h	Mean		
				sec.	μ	μ	μ	μ	μ	sec.	sec.	sec.	sec.	sec.	μ	d. h.
7½° E. to 22½° E. Zone 1.	Taunus‡	G.	N–S.	15·0	—	—	—	—	0·8	—	—	—	—	6·9	2·3	30
	,,	G.	N–S.	2·5	—	—	—	—	0·4	—	—	—	—	4·1	0·7	26
	Eger§ ..	M.	N–S.	9·7	2·6	2·9	2·7	2·6	2·7	—	—	—	—	—	5	11 11 11 17 11 23
	,,	B.	E–W.	12	3·0	3·1	2·9	2·8	3·0	—	—	—	—	—	7	30 11 30 17
	Heidelberg	W.	E–W.	11·4	0·7	0·7	0·9	0·8	0·8	6·5	6·7	6·6	6·9	6·7	6·6	11 18
	Strasbourg	G.	N–S.	10·6	5·9	6·2	5·8	5·3	5·8	6·2	6·2	6·3	6·1	6·2	13·0	12 1
	,,	G.	E–W.	12·0	3·7	3·8	3·8	3·2	3·6	6·2	6·2	6·1	6·3	6·2	10·8	11 13
	,,	G.	Z.	11·5	1·8	1·9	1·9	2·0	1·9	6·2	6·3	6·2	6·2	6·2	8·8	11 18
	,,	W.	N–S.	9·4	4·4	5·1	5·0	5·2	4·9	6·2	6·2	6·3	6·2	6·2	14·3	11 18
	,,	W.	E–W.	8·5	2·2	2·6	2·9	2·7	2·6	6·1	6·0	6·2	6·1	6·1	11·0	11 13
	,,	W.	Z.	3·3	1·7	1·8	2·0	2·1	1·9	5·5	5·5	5·5	5·5	5·5	7·3	11 18 12 1
	Vienna ..	W.	N–S.	9·4	0·8	1·1	1·1	1·0	1·0	6·1	6·0	6·1	6·1	6·1	3·2	11 13
	,,	W.	E–W.	11·2	0·7	0·9	1·0	0·9	0·9	5·9	6·1	6·1	6·3	6·1	3·4	13 1
	Munich ..	W.	N–S.	9·0	1·2	1·7	1·8	1·5	1·6	6·1	6·2	6·3	6·2	6·2	4·9	11 13
	,,	W.	E–W.	8·9	1·1	1·7	1·8	1·4	1·5	5·9	6·1	6·1	6·0	6·0	5·4	11 18
	Zürich‖ ..	Q.P.	N–S.	3·0	0·9	1·0	1·0	1·1	1·0	5·6	5·5	5·6	5·7	5·6	7·0	11 18
	,,	Q.P.	E–W.	3·0	0·9	1·0	0·9	1·1	1·0	5·4	5·5	5·4	5·7	5·5	7·0	11 18
	Chur ..	Q.P.	E–W.	3·4	0·5	0·5	0·5	0·5	0·5	5·6	5·5	5·6	5·4	5·5	2·4	11 13
	Zagreb ..	W.	NE–SW.	9·6	0·9	1·1	1·1	1·0	1·1	5·8	5·9	6·0	5·9	5·9	3·0	11 13
	,,	W.	NW–SE.	8·7	0·7	0·8	0·7	0·6	0·7	6·0	6·2	6·2	6·1	6·1	2·5	11 13
	Cape Town	M.S.	E–W.	7	0·5	0·5	0·5	0·6	0·5	5·5	5·6	5·6	5·5	5·6	1·2	29 13
22½° E. to 37½° E. Zone 2.	Helsingfors	M.	N–S.	12	1·0	0·9	0·9	1·0	1·0	4·9	5·1	4·9	5·4	5·1	3·5	21 7
	,,	M.	E–W.	12	1·1	1·0	1·0	1·1	1·0	5·2	5·0	5·5	5·1	5·2	3·6	6 7
	Pulkovo ..	G.	N–S.	14·8	0·7	0·7	0·7	0·8	0·8	5·5	5·4	5·5	5·6	5·5	2·3	6 7
	,,	G.	E–W.	13·4	0·8	0·9	0·9	1·0	0·9	5·7	5·4	5·5	5·8	5·6	2·9	4 18
	,,	G.	Z.	14·0	1·0	1·1	1·1	1·1	1·1	5·6	5·6	5·7	5·9	5·7	2·7	6 7 6 18
37½° E. to 52½° E. Zone 3.	Kučino* ..	G.	N–S.	23·8	0·9	0·8	0·8	1·0	0·9	6·0	6·0	6·3	6·2	6·1	2·7	22 18
	,,	G.	E–W.	22·6	0·9	0·8	0·9	1·0	0·9	6·1	6·1	6·2	6·1	6·1	2·7	21 12
	,,	G.	Z.	11·1	0·9	0·9	1·0	1·0	1·0	6·0	6·2	6·2	6·1	6·1	2·8	21 12
97½° E. to 112½° E. Zone 7.	Batavia	W.	N–S.	6·8	0·7	0·8	0·5	0·3	0·5	5·8	5·7	5·6	6·0	5·7	2·2	25 7
	,,	W.	E–W.	6·6	0·7	0·9	0·4	0·2	0·5	5·6	5·7	5·6	5·8	5·6	2·8	25 7
112½° E. to 127½° E. Zone 8.	Zi-Ka-Wei	G.	Z.	13	0·5	0·5	0·5	0·5	0·5	4·5	4·5	4·5	4·5	4·5	1·5	11 18
	Perth ..	M.S.	N–S.	12	4·5	4·4	4·1	3·8	4·2	5·1	5·0	4·7	4·8	4·9	6·6	18 13
127½° E. to 142½° E. Zone 9.	Tokyo ..	M.	N–S.	12·0	1·7	1·9	1·5	1·3	1·6	3·9	3·9	4·0	3·7	3·9	10·9	5 18
	,,	M.	E–W.	12·0	2·4	2·5	2·1	1·3	2·1	4·1	4·1	4·1	3·7	4·0	8·0	6 13
142½° E. to 157½° E. Zone 10.	Riverview	W.	N–S.	8·5	0·7	0·7	0·7	0·7	0·7	3·9	4·0	4·0	3·8	3·9	2·4	2 18
	,,	W.	E–W.	9·4	0·8	0·7	0·7	0·8	0·8	3·8	3·9	3·8	3·8	3·8	3·4	19 1
	Melbourne	M.S.	E–W.	12	0·5	0·5	0·5	0·5	0·5	5·6	5·7	5·8	5·9	5·7	2·5	18 13

‡ One observation daily at 9h.
‖ See footnote 2 to Table 1.
§ Observations for 23h., 5h., 11h. and 17h; period = 5 sec. to 8 sec.
* Observations for 0h, 6h, 12h and 18h, G.M.T.

TABLE II—*continued.*

Locality	Observatory	Seismograph			Mean amplitude					Mean period					Maximum amplitude	Time of maximum amplitude	
		Type	Component	Free period	1h	7h	13h	18h	Mean	1h	7h	13h	18h	Mean			
				sec.	μ	μ	μ	μ	μ	sec.	sec.	sec.	sec.	sec.	μ	d.	h.
172½° E. to 172½° W. Zone 12.	Apia ..	W.	N-S.	7·4	2·3	2·1	2·5	2·3	2·3	4·3	4·5	4·1	4·3	4·3	5·7	30 31	18 7
	,,	W.	E-W.	9·0	2·0	1·8	2·0	1·8	1·9	4·9	4·6	4·8	4·7	4·7	3·7	19	1
	Wellington	M.S.	N-S.	10·3	0·8	0·7	0·8	0·9	0·8	4·9	5·0	4·8	5·0	4·9	3·4	29	1
	,,	M.S.	E-W.	9·8	1·0	1·0	1·0	1·0	1·0	4·7	4·8	4·7	5·0	4·8	4·2	28	18
157½° W. to 172½° W. Zone 13.	Honolulu	M.S.	N-S.	12	10·2	9·2	10·0	10·3	9·9	5·2	5·1	5·5	5·2	5·2	19·2	12	1
	,,	M.S.	E-W.	12	9·8	9·3	8·9	8·8	9·2	5·2	5·2	5·2	5·1	5·2	20·4	12	1
127½° W. to 142½° W. Zone 15.	Sitka† ..	W.A.	N-S	6·5	(0·7)	(0·7)	(0·7)	(0·8)	(0·7)	(5·5)	(5·8)	(6·0)	(6·0)	(5·9)	(2·3)	11 11	13 18
112½° W. to 127½° W. Zone 16.	Victoria ..	M.S.	N-S	12·0	1·0	1·0	1·0	0·9	1·0	5·2	5·0	4·9	4·9	5·0	3·6	3	13
	,, ..	M.S.	E-W.	12·0	1·3	1·2	1·2	1·1	1·2	5·4	5·3	5·3	5·2	5·3	4·0	3	1
	Pasadena	W.A.	N-S.	4·5	0·3	0·3	0·3	0·2	0·3	6·2	6·3	6·3	6·2	6·2	0·8	19	13
	,,	W.A.	E-W.	10	0·8	0·7	0·7	0·6	0·7	6·7	6·7	6·9	6·7	6·8	1·5	12	1
97½° W. to 112½° W. Zone 17.	Tucson ..	W.A.	N-S.	10	0·3	0·2	0·2	0·2	0·2	6·2	5·9	6·1	5·6	5·9	0·9	12	1
82½° W. to 97½° W. Zone 18.	Florissant	G.	N-S.	12	0·3	0·3	0·2	0·3	0·3	6·2	6·1	5·9	6·0	6·0	0·8	30	18
	,,	G.	E-W.	12	0·3	0·3	0·3	0·3	0·3	6·2	6·3	6·3	6·3	6·3	0·8	1	1
	,,	G.	Z.	12	0·5	0·5	0·4	0·4	0·4	6·2	6·1	6·2	6·1	6·2	1·3	1	1
67½° W. to 82½° W. Zone 19.	Ottawa ..	M.S.	N-S.	12·0	0·4	0·3	0·3	0·4	0·4	5·5	5·5	5·6	5·5	5·5	1·6	30	18
	,, ..	M.S.	E-W.	12·0	0·4	0·4	0·3	0·4	0·4	5·4	5·2	5·3	5·3	5·3	1·2	1	1
	Harvard ..	M.S.	N-S.	12	1·0	0·9	1·1	1·1	1·0	4·8	5·2	5·2	5·0	5·0	3·0	1	1
	,, ..	M.S.	E-W.	12	0·9	0·9	1·0	0·9	0·9	5·1	4·7	5·0	5·0	5·0	3·0	1	1
	Georgetown	G.	Z.	9·3	1·3	1·3	1·3	1·3	1·3	5·8	5·7	5·7	5·8	5·8	3·9	31	7
	La Paz ..	Bf.	E-W.	12	0·4	0·4	0·5	0·5	0·5	5·8	5·9	6·1	6·0	6·0	0·7	—	—
37½° W. to 52½° W. Zone 21.	Ivigtut ..	W.	N-S.	12·2	3·3	3·1	3·1	3·3	3·2	6·2	6·1	6·1	6·2	6·1	11·8	21	13
	,, ..	W.	E-W.	12·4	3·2	2·9	2·7	3·1	3·0	6·0	6·0	5·9	5·9	6·0	14·1	11	7
	,, ..	W.	Z.	5·3	5·9	6·0	5·3	6·2	5·9	6·0	6·0	6·0	6·0	6·0	24·8	21	7
7½° W. to 22½° W. Zone 23.	Scoresby Sund ..	G.	E-W.	13·1	4·0	4·1	4·1	4·2	4·1	6·4	6·5	6·5	6·6	6·5	14·8	11	13
	Reykjavik	M.	E-W.	6·7	5·4	6·3	8·4	8·4	7·1	5·8	5·7	5·7	5·7	5·7	33·6	11	7

† Tabulations incomplete.

TABLE II—*continued*—SUPPLEMENTARY DATA.

Stuttgart. No data are available for January 1930 but the following values have been obtained from the Galitzin–Wilip seismograms of January 1931.

STUTTGART. MICROSEISMS DURING JANUARY 1931.

Component	Mean amplitude.					Mean period.				
	1h	7h	13h	18h	Mean	1h	7h	13h	18h	Mean
	μ	μ	μ	μ	μ	sec.	sec.	sec.	sec.	sec.
N–S	0·6	0·6	0·5	0·5	0·6	6·2	6·3	6·2	6·1	6·2
E–W	0·5	0·5	0·5	0·5	0·5	6·2	6·2	6·1	6·1	6·2
Z	0·6	0·7	0·6	0·6	0·6	6·2	6·3	6·2	6·2	6·2

Rome. The type of seismograph is unsuitable for accurate measurements of the microseisms. Examination of the charts shows that disturbances occurred from the 6th to 13th, on the 18th and 24th and from the 26th to the end of the month. The largest microseisms were recorded from 12h. on the 12th to 22h. on the 12th; fairly large movements also occurred on the 27th and 29th.

Helwan. Milne Shaw seismograph with magnification 250. During January 1930 there were traces of microseisms every day the period usually being from 4 sec. to 6 sec. On only two days, the 11th and 15th, did the amplitudes as recorded reach 0·5 mm; the largest microseisms were recorded on the 15th, the maximum movements being of period 5 sec. and amplitude 3μ.

Tananarive. The magnification of the Mainka N–S and E–W seismographs is too low for the study of microseisms, the maximum amplitudes being only 1·4μ (0·2 mm. on the seismograms).

Manila. Records are available during January 1930, of the N–S and E–W components from a Wiechert seismograph. From the 1st to 5th of the month there were no microseisms in groups but almost continuous oscillations of 5 sec. period and amplitude about 1μ. Microseisms in groups were recorded from the 6th to 14th with periods about 5 sec. and mean amplitudes 3μ; the maximum amplitudes (5μ) occurred from 13h. on the 8th to 7h. on the 9th and at 7h. on the 13th. The microseisms were insignificant during the latter half of the month.

Adelaide. A Milne Shaw seismograph (magnification 150) was in operation. The maximum amplitudes were about 2μ (0·3 mm. on the records).

Chicago. The microseisms were too small to be shown in the N–S and E–W Milne Shaw seismograms (magnification 150). The largest movements were about 1μ.

Toronto. Milne Shaw seismographs with magnification 150. The largest amplitudes (3μ) were registered on the 1st, 3rd, 11th–12th, 18th, 20th–21st and from the 28th to 30th.

Seattle. Records are available for the month of the survey but the instrumental constants are not known. Spells of microseismic disturbance occurred from the 1st to 5th, from the 10th to 11th and from the 15th to 19th, the largest amplitudes occurring on the 3rd.

Rio de Janeiro. Milne Shaw seismograph. There was no appreciable microseismic disturbance during January 1930. The following table, giving the number of days in each month from 1929 to 1932 when microseisms occurred, shows that they are more often to be found in the seismograms for winter months ; thus, although Rio is not very far south of the equator, the annual variation is the reverse of that in the northern hemisphere.

RIO DE JANEIRO. NUMBER OF DAYS SHOWING MICROSEISMS, 1929–1932.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1929 ..	4	3	3	5	7	8	8	6	2	7	2	4
1930 ..	0	0	10	4	4	4	10	10	6	10	7	3
1931 ..	8	5	3	5	8	6	10	3	6	6	2	0
1932 ..	2	1	0	5	7	4	1	6	6	1	3	1
Total ..	14	9	16	19	26	22	29	25	20	24	14	8

Scoresby Sund. On a number of days with large microseisms tabulations could not be made for the N–S component owing to faintness of the traces. Comparisons of the amplitudes for the two horizontal components on days when both could be measured indicate that they are equal within the accuracy of the determinations.

Reykjavik. For the N–S component tabulations are only available from the 17th to 31st of the month ; the mean amplitudes and periods for both components during this interval are given below.

Component	Mean amplitude.					Mean period.				
	1h	7h	13h	18h	Mean	1h	7h	13h	18h	Mean
	μ	μ	μ	μ	μ	sec.	sec.	sec.	sec.	sec.
N–S	6·1	7·4	7·2	6·5	6·8	5·8	5·7	5·7	5·7	5·7
E–W	5·7	6·6	8·7	8·4	7·3	5·8	5·6	5·6	5·7	5·7

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