36. *A Discussion on the Results of a Statistical Investigation of Earthquake Phenomena.*

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(Read June 16, 1936.—Received June 20, 1936.)

Introduction.

Before giving a summary or entering into the discussion on the results of my statistical investigations of earthquakes, I shall set down a short note on the development of statistical problems in seismology, most of which may be seen in books on seismology.[1]

Statistical investigations on the frequency and periodicity of earthquakes have been made since the early days of seismology by many seismologists in Japan and elsewhere, such as J. Milne, C. G. Knott, A. Schuster, C. Davison, and others abroad, and F. Ômori, K. Honda, T. Terada, A. Imamura, K. Shiratori, Saem. Nakamura, S. Ono, and others in Japan. The same problems have recently been attacked by M. Ishimoto, T. Matuzawa, Ch. Tsuboi, N. Miyabe, and others.

In 1897, Professor Schuster communicated a paper to the Royal Society of London on lunar and solar periodicities of earthquakes, which was to a large extent a critical examination of the results given in Knott's earlier paper on the same subject. It is important to refer to Schuster's critique, which is a criterion of the reality of an apparent periodicity in statistics of the kind we are now dealing with.

The question is purely one of probabilities, and Schuster, by developing a result given by Rayleigh[2] in 1880, arrived at a conclusion which may be stated in the following terms: Suppose that we have n disconnected events occurring at random within a given interval of time, and that we consider the probability of the frequency of these events being expressed harmonically by a Fourier Series in which the periods are submultiples of the interval of time; then it is shown that the probability of any amplitude lying between the limits r and $r+dr$

1) "A Historical Sketch of the Development of Seismology in Japan", by T. Terada and T. Matuzawa, C. G. Knott's "The Physics of Earthquake Phemomena", and C. Davison's "A Manual of Seismology".

2) Lord RAYLEIGH, "On the resultant of a large number of vibrations of the same pitch and of arbitrary phase", *Phil. Mag.*, [v], **10** (1880).

is

$$\frac{1}{2}nrdre^{-\frac{nr^2}{4}};$$

that the expectancy for the value of the amplitude is $\sqrt{(\pi/n)}$; and that the probability, W_p, of the amplitude exceeding any given value p is

$$W_p=e^{-\frac{\pi p^2}{4}}.$$

It is important that the catalogues which are being subjected to analyses should be as complete as possible and should cover a long series of years. Should the total number of earthquakes included be small, analysis of the figures may produce a period that does not really exist. Schuster has shown that, if earthquakes occur at random, harmonic analysis may give an apparent seismic period of amplitude $\sqrt{(\pi/n)}$, where n is the number of earthquakes. But earthquakes occur not at random, but in groups. Thus, in any isolated record, unless the amplitude exceeds this amount or expectancy, the period indicated by the analysis cannot be regarded as established. Should, however, the maximum epochs of a particular period approximately agree for neighbouring regions or for the same region at different intervals of time, existence of the period may be regarded as probable even if the calculated amplitude were to fall below expectancy.

For example, in Fig. 1 are shown curves representing the annual period in three neighbouring countries for the years 1865～1884. The continuous curve is that for Austria, the amplitude being 0·37, the number of earthquakes 461, and the expectancy 0·08. The broken line represents the annual period for Hungary, Croatia, and Transylvania, the amplitude being 0·31, the number of earthquakes 384, and expectancy 0·09. The dotted line shows the same period for Switzerland and the Tyrol, the amplitude being 0·56, the number of earthquakes 524 and the expectancy 0·08. Even had the amplitude in each case fallen below expectancy, the fact that the maximum epochs occur at the end of *January, December, and Jauary* would support the reality of the period.

C. G. Knott summarised his arguments on the cause of earthquakes as follows: "The cause of earthquakes is probably to be referred to the earth's heterogeneity of structure or to the inequality of stress due to irregularities of its surface. Rupturing or yielding is not determined by the amount of stress only; it depends in great measure upon how the stress is applied. For rupture to take place the stress must be different directions; and the difference between the greatest and

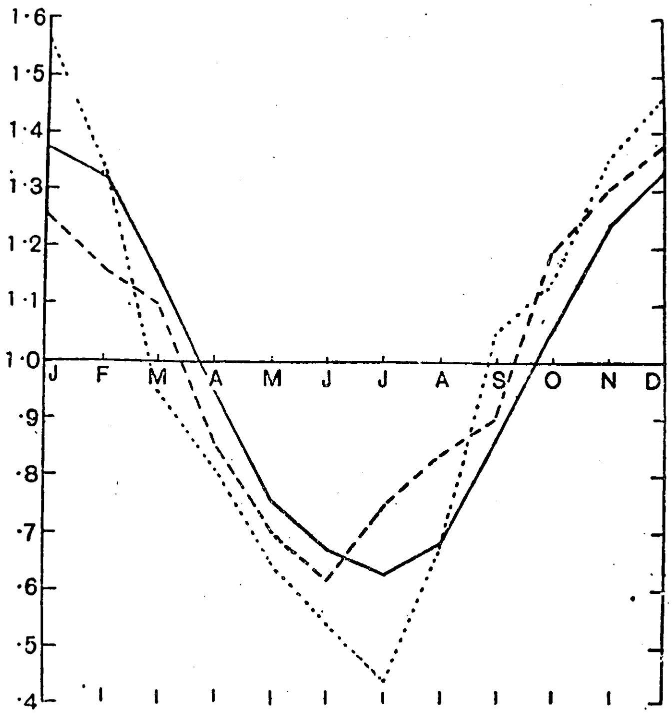

Fig. 1. Annual periodicity of earthquakes in (i) Austria, (ii) Hungary, Croatia and Transylvania, and (iii) Switzerland and the Tyrol.

least stresses is an important datum in estimating the tendency to break. So far as can be judged, the only periodic stresses that of period long enough to tell upon the earth's substance are the fortnightly, monthly, semi-annual, and annual tides, the annual variation of snowfall, and the steady annual and perhaps semi-annual oscillation of barometric pressure over the earth's surface. Inasmuch as the earthquake frequency reaches its maximum in winter wherever there is a marked winter season, we must pass from the annual tidal stress due to the sun as of little account. We seem, however, to find in the accumulations of winter snow, and in the long period oscillations of the atmospheric pressure, two possible determining factors in earthquake frequency".

The views advanced by Dr. Davison differ from this in only one respect. He attaches more importance to the annual changes in pressure over the seismic district itself.

The annual and seasonal variation in the frequency of earthquakes was for long extensively studied by F. Ômori[3], who discussed the effects of barometric pressure on the annual and diurnal variations in earthquake frequency. In the meantime he studied the changes in sea-level at different mareographical stations and came to the conclusion that the combined effect of the barometric and tidal pressures is an important secondary cause of earthquakes.

Certain sympathetic or contagious interrelations between the activities of distant earthquake zones have also been suspected by Ômori, who cited many examples of Japanese destructive earthquakes that occurred within a short time of the occurrence of severe ones in other parts of the world.

K. Honda[4], in his investigation of level changes in wells, noticed some relation between the frequency of earthquakes and tidal phases.

A. Imamura[5] studied the synodic-monthly distribution of the frequency of earthquakes. The results obtained are rather complicated. Four maxima or two were found for earthquakes of submarine and inland origins, the results being explained by interference of effects due to barometric and tidal pressures.

T. Terada[6] investigated the relation between the annual variations in barometric gradient and that in the frequency of earthqukes in different regions and found that the latter shows a parallelism with the component of the gradient in a certain direction proper to each region. He[7] also drew attention to the fact that an apparent or "phantom" periodicity may be brought about by a quite arbitrary sequence of events.

Saem. Nakamura[8] studied the frequencies of days with 0, 1, 2∼9 earthquakes recorded instrumentally, with reference to the data observed in Tokyo during four years. On comparing the results with theoretical expectations corresponding to random distribution, it was found that the number of days with no shock was less than the theoretical value, while those with one or two shocks exceeded expectation.

Rebeur Paschwitz's horizontal pendulum for registering the tilting of the crust relative to the direction of gravity having been installed in the Kamigamo Observatory, observations were made by Shida[9] and

3) F. Ômori, *Report I. E. I. C.*, **2** (1894); **25** (1899); **30** (1900); **32** (1900); **54** (1906); **57** (1906). *Publ. I. E. I. C.*, **8** (1902). *Bull. I. E. I. C.*, **2** (1902), No. 1. *Jour. Coll. Sci., Tokyo*, **11** (1899).
4) K. Honda, *Publ. I. E. I.C.*, **18** (1904).
5) A. Imamura, *Report I. E. I. C.*, **18** (1904).
6) T. Terada, *Jour. Met. Soc.*, **28** (1909), 1.
7) T. Terada, *Proc. Tokyo Physico-Math. Soc.*, **8** (1916), 492.
8) Saem. Nakamura, *Jour. Met. Soc.*, **39** (1920).
9) Prof. Shida, *Memoirs Coll. Sci., Kyôto*, **4** (1912), 1.

his assistants since Feb. 1910. In spite of the considerable distance of the station from the sea, the tilting due to the tidal load was remarkable compared with the component due to variation in the level directly derivable from the tide-generating potential, so that the difficulties that had to be overcome in analysing the different components were considerable. To give an example, he had to take account of the actual tides instead of assuming simple ideal tides, as was done in his previous work. His results thus obtained are interesting from the seismological as well as from the geophysical point of view, in that they show a reliable measure of the actual deformation of the crust due to the water load applied along the coast.

On the occasion of the recent Tazima Earthquake, K Suyehiro noticed the remarkable fact that most of the strong earthquakes in the Japan Sea coast of the San'indô occur within a few years after destructive shocks have occurred in the Pacific zone.

As a secondary cause of earthquakes, the effects of surface loading over a circular area were considered by H. Nagaoka[10]. Even a very remote centre of atmospheric depression can affect the equilibrium of the earth's crust and give rise to pulsatory motions. Later, he treated an allied problem in connection with the effect of a barometric gradient on earthquake frequency, and showed that rupture of the crust is to be expected near the maximum of the gradient. As to pulsatory motions, he discussed the stationary vibration of one end of a semi-infinite solid with two parallel edges.

A similar problem of surface loading was treated later by K. Terazawa[11], when he discussed the periodic disturbances of level due to the load of neighbouring oceanic tides.

M. Ishimoto[12] after a study of the periodicity of earthquake occurrences stated that could be explained as arbitrary events.

In presenting here a resume of my papers hitherto published, based on investigations extending over a period of years, I will refer to investigations made and theories advanced by a number of seismologists, to which I will add new opinions of my own.

Resume and Discussions.

1. Relation between Tidal Phases and Earthquakes.

In my first paper[13], the reduced frequency of after-shocks, was

10) H. NAGAOKA, *Proc. Tokyo Physico-Math. Soc.*, **3** (1906), **6** (1912).
11) K. TERAZAWA, *Jour. Coll. Sci., Tokyo*, **37** (1916), Art. 7.
12) M. ISHIMOTO, A report read before the P. M. C. of Japan; not yet published.
13) S. YAMAGUTI, *Bull. Earthq. Res. Inst.*, **8** (1930), 393.

calculated for comparing various curves corresponding to different epochs and to different localities, but this time, the frequency alone for the total epochs of each regions was taken and plotted as ordinate against the tidal phase.

The relation between the frequency of the after-shocks of the Great Kwantô Earthquake and the tidal phases at Yokosuka, are shown in Fig. 2. For convenience, the region including the origin of the after-shocks is divided as follows:

A. Area including Sagami Bay and the Province of Sagami as the main part.

B. Bôsô peninsula and near its S. E. coast.

C. Tokyo and its environs.

The total number of after-shocks, N=479.

The frequency in occurrence of after-shocks usually shows a maximum, slightly before low water, suggesting a secondary maximum frequency also about one and a half hours before high water.

The fact that the curves for different independent epochs and for different localities usually show some characters common to the two curves as revealed in the mean curve of long duration, or in the sum curve for these localities, may be regarded as proof of the existence of a certain physical relation between the frequency in occurrence of shocks and the tidal phase.

The frequency in the after-shocks of the Tango Earthquake, N=1464, March 7, 1927～July 16, 1928, shows a conspicuous maximum near low water and also a secondary maximum about one and a half hours after high water at Wazima, as shown in Fig. 3. These relations, referred to the tides at Kôbe, are not so conspicuous as those referred to the tides at Wazima; They are also shown in the case of after-shocks of the Tazima Earthquake, N=358, May 23～June 17, 1925, referred to the tides at Wazima and at Kôbe, as shown in Fig. 5. The existence of the difference between the effects of tides at Wazima and Kôbe on the occurrence of after-shocks of the Tango and Tazima Earthquakes may be regarded as showing the real physical relations between the frequency of shocks and the tidal phase, and not an arbitrary occurrence of the relation.

The fact that the earthquake frequency and tide curves for the after-shocks of these four great earthquakes, namely, the Kwantô, Tango, Tazima, and Ômati, show unmistakable resemblance to one another, especially with regard to the maximum frequency at low tide, may be considered as pointing to a real physical relationship between the two phenomena of earthqnakes and tides.

Prof. T. Matuzawa's investigation[14] on the probability of the existence of a relation between earthquake frequency and tidal phase, has given 0·214, as its value, assuming that the relation might hold quite accidentally.

The shocks on the northern side of the Yamada Fault in Tango have their maximum of frequency about low water and the secondary maximum about high water. The shocks in the sea bed near Tango show an entirely opposite course compared with the above as shown in Fig. 4—a result that may suggest some essential differences in the mechanism of the earthquakes for the two origins, i. e., in the sea bed and on the land north of the Yamada Fault.

The fact that amplitudes of frequency curves for the after-shocks of four different regions referred to the tidal phases, are as a rule, greater than those referred to the solar time intervals, as shown in Figs. 12 and 13 in the earlier paper above cited, shows how conspicuous is the tidal effect on the occurrence of shocks compared with the other elements that are supposed to induce shocks.

The physical explanation of these results may be as follows:

About middle water, the earth's crust, acted upon by many forces, is assumed to be in equiliblium, which may be broken down at low water by decrease in the tidal load (an increase at high water), with earthquakes as the result.

The result of investigations on tiltings of the earth's crust made by Prof. Ishimoto, with his ingenius instrument at Miyatu and Kawabe[15] immediately after the Great Tango Earthquake, and that made by Prof. Ishimoto and Mr. R. Takahasi[16], at Itô in Idu, and also that made by Mr. Takahasi[17] at Aburatubo in Sagami, may support the above explanation regarding the effect of tides on the occurrence of earthquakes.

Only the amplitudes of frequency curves for the Ômati Earthquake, N=433, Nov. 11, 1918～Feb. 28, 1919, referred to the tide at Wazima and to solar time, are almost alike. This result appears perfectly reasonable if one takes into consideration the fact that Ômati is situated much farther from the sea than the other three districts, and that the effects of some other elements on the occurrence of shocks, such as daily variations in atmospheric pressure, may operate.

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14) T. MATUZAWA, *Bull. Earthq. Res. Inst.*, **14** (1936), 38.
15) M. ISHIMOTO, *Bull. Earthq. Res. Inst.*, **4** (1928), 203.
16) M. ISHIMOTO and R. TAKAHASI, *Bull. Earthq. Res. Inst.*, **8** (1930), 427.
17) R. TAKAHASI, *Bull. Earthq. Res. Inst.*, **7** (1929), 95.

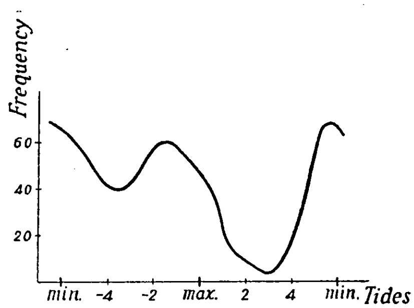

Fig. 2. Frequency curve of after-shocks of the Great Kwantô Earthquake, referred to tides at Yokosuka. Sept. 2∼Oct. 1. (A+B+D)

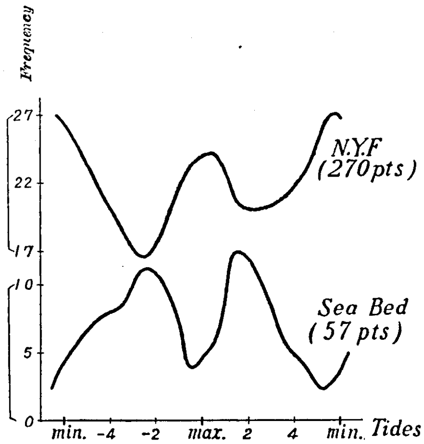

Fig. 4. After-shocks of the Tango Earthquake, referred to tides at Wazima, March 11, 1927∼July 16, 1928. N. Y. F. means north side of Yamada Fault.

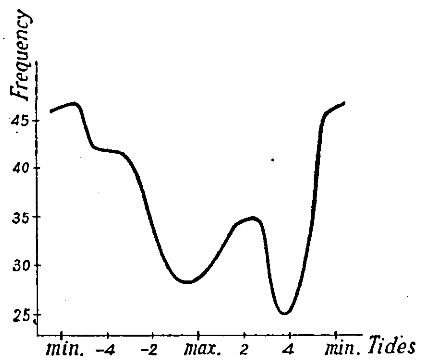

Fig. 6. After-shocks of the Ômati Earthquake, Nov. 11, 1918∼Feb. 28, 1919, referred to tides at Wazima.

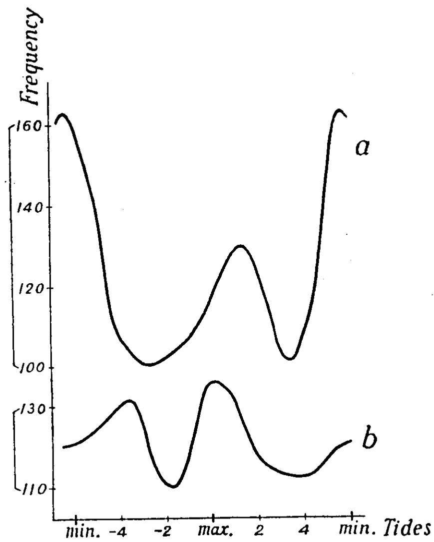

Fig. 3. After-shocks of the Tango Earthquake,
(*a*) referred to tides at Wazima,
(*b*) referred to tides at Kôbe.
March 7, 1927∼July 16, 1928.

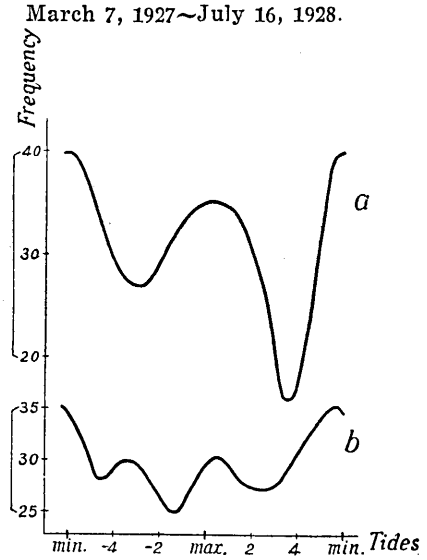

Fig. 5. After-shocks of the Tazima Earthquake, May 23∼June 17, 1925,
(*a*) referred to tides at Wazima,
(*b*) referred to tides at Kôbe.

2. On Time and Space Distribution of Earthquakes.

a) Fissure line.

The epicentres of earthquakes that occurred in the Kwantô Districts were plotted on a map for each month and joined by a straight line successively in the order of time. The number, n, of the directions of these straight lines falling in the direction within each sector of an azimuth angle of 15°, which is formed by dividing all directions into 24 parts, were counted and plotted in vector diagrams against the azimuth angle, N-direction being taken as zero, as shown in Fig. 1, in my first paper[18] "On Time aud Space Distribution of Earthquakes". The vector diagram for n's were transformed into the corresponding *xy-diagram* and arranged as in Fig. 4, *a*, taking the directions of the monthly mean pressure gradients at Iwaki as the respective origins of directions, an error of ±7°5 having been allowed for. Similar *xy-diagrams* were also constructed for deviations of n from the yearly mean. The results are shown in Fig. 4, *c*, in the same paper, in which the dotted lines on the left-hand quarter are the means of the four quadrants. From this mean curve distinct maxima are seen to be somewhere near 0°, 45°, and 90°. The maximum at 45° may correspond to the direction of maximum shearing stress in the earth's crust due to the pressure gradient, while the maxima at 0° and 90° may mean that a tangential or normal stress on a preexisting fissure might induce a succession of earthquakes along that fissure line.

b) Preferential ratios.

Before inquiring into the physical meaning of sequnces of earthquakes in different regions, it is neccessary to make a calculation of the statistical probability of sequence for the case in which the earthquakes occur quite at random. The following calculation was made for this purpose:

Let N_k, N_l, ...be the number of earthquakes that occurred in region, k, l,... respectively during the epoch taken. Then the probability P_{kl} that the earthquakes will occur in region l, next to k may be expressed by $P_{kl}=\dfrac{N_k N_l}{\sum\sum N_k N_l}$, while the expected number N' to occur at l, next to k, is given by $N'=P_{kl}\sum N$. The value of the ratio r of the actual number of occurrences N_0 to the calculated number N', that is $r=N_0/N'$, were calculated.

In the paper above cited, the severe earthquakes, 420 in number,

18) S. YAMAGUTI, *Bull. Earthq. Res. Inst.*, **11** (1933), 46.

that convulsed different parts of the world during the period of 31 years from 1900 to 1931 were taken from Rikwa-Nenpyô and geographically classified into 8 groups according to regions of occurrence, and the values of the preferential ratios r calculated as shown in Table IV, *a*, and in Fig. 8, *a*, *b*.

Such preferential ratios as have values greater than 1·43, may be regarded, at least, as suggesting that in such particular sequences of regions an earthquake is liable to be followed by another. Prof. Matuzawa's criterion for the accidental and the real occurrence of sequences of earthquakes seems to be taken as $1 \pm 0{\cdot}241$, approximately, as above explained.

In other earthquakes, the sequence of regions, Japan → South America, and South America → Japan, always give preferential ratios greater than 1·43, which result may be regarded as supporting the statement that an earthquake in Japan is liable to be followed by another in the antipodes. The same result may also be obtained by the other method of investigation described in a paper[19], "Statistical Relation between the Frequencies of Earthquakes in Japan and Other Parts of the World".

We also calculated the preferential ratios given quite at random by throwing a dice 400 times in succession. The result shows that the range of fluctuation in the values of preferential ratios lies between 0·68 and 1·43. The pairs of regions therefore that have values of preferential ratios decidedly greater than 1·5 and less than 0·6, may at least be suspected to have some particular physical relation to sequences of earthquakes.

Moreover, no pair of regions for which equally large ratios are obtained for the reversed sequences of earthquakes, such as between Japan and South America, could be found in this artificial case.

c) Periodicity of Earthquakes.

The time intervals from an occurrence of a great earthquakes to the next one in the world, $N=420$, were obtained, and the frequencies of these intervals for every 10 days were counted and plotted as ordinates, the days of the intervals being taken as abscissa. The general trend of the curve shows the random occurrence of the earthquakes. We calculated the frequency f for purely random occurrences, assuming $f=ae^{-bt}$, and obtained the deviations of the actual frequencies from this theoretical value of f, which are shown in Fig. 9 in my first paper above cited. In order to satisfy ourselves that the periodicity of the

19) *Bull. Earthq. Res. Inst.*, **10** (1932), 36.

deviation curve is not due to the apparent one proper to any accidental phenomena, we also tried to take the half intervals or else the overlapping intervals of days for comparison. The features of these curves remained essentially the same.

For the particular pairs of earthquakes corresponding to $r>1{\cdot}25$, $N=118$, and $r>1{\cdot}6$, $N=78$, which are results from the previous investigation with respect to the sequence of earthquakes, the same methods were used.

The frequency curves of time intervals of the great earthquakes of the world seem to show a period of 27·5 days. The same period is obtained whether we choose 5 days or 10 days for the division of the time axis of the curve. This period is also obtained in the case of "deep" Japanese earthquakes as shown in Fig. 7 in the paper[20], "Distribution of Earthquakes in Japan". Moreover, periods that are multiples of 27·5 days, namely periods of about 55 and 105 days, are also observed from those curves both for the worlds great earthquakes and for the "deep" Japanese earthquakes.

The period of 27·5 days seems to correspond to the 27·3 days period of rotation of the sun relative to the earth.

The reason for the existence of this period is not yet clear, but according to investigations on the sun made by the Wilson Astronomical Ovservatory as well as by the Greenwich Observatory, it seems that the great eruptions of hydrogen gas from the sun's surface occur with this period, so that it may be the cause of variations in a certain solar force or forces acting on the earth, but of which nothing is yet known to us, the result of which may be regarded as inducing the world's great earthquakes and the "deep" earthquakes of Japan.

3. Relation between Cyclones or Atmospheric Pressure Distribution and Earthquakes.

Some preliminary investigations on the relation between cyclones and earthquakes were made by the writer. First, he counted the number J representing shifts of epicentres in E→W or W→E direction in almost the same latitude in the Tôhoku region and Hokkaidô for every month during a period of 7 years, from June, 1924 to May, 1931, and compared it with the corresponding number of tracks of cyclones that traversed these regions. Taking, instead of J, the ratio r of J to the whole number, *an xy-diagram* was drawn as shown in Fig. 7, *c*, in his paper[21], "On Time and Space Distribution of Earth-

20) *Bull. Earthq. Res. Inst.*, **11** (1933), 500.
21) *loc. cit.*, 18).

quakes". In this diagram the curved line was constructed by joining the mean point of each y corresponding to each x, and an ellipse drawn from sight so as to contain all the points properly. I also calculated the correlation coefficient of r with respect to the number of tracks of cyclones, applying the ordinary formula, and obtained 0·47 as the value.

The result may suggest the possible existence of a close relation between earthquakes and cyclones.

Second, I counted the number n for three successive months, (a) for the "deep" earthquakes during 6 and a half years from Jan., 1926 to June, 1932, (b) for the "conspicuous and rather conspicuous" earthquakes that occurred in the region from Kyûsyû to the sea off Sanriku, (d) for the "felt" earthquakes that occurred in the region from Wakayama to Idu. At the same time I counted the number of tracks of cyclones that passed across the "deep" earthquake zone over a length of ± 1000 km, measured from the origin near the mouth of the Bay of Ise along a line perpendicular to the Japanese arc for 3 successive months.

Looking at these curves of n plotted against the time axis, there seem to exist certain fluctuations of long period superposed upon an annual period. Thus, I assumed that the curve for earthquakes, E consists of two parts, the one of longer period E_l and the other of annual periods E_a and $E=E_l+E_a$. Similarly, for the cyclones, I denoted the frequencies of cyclones by $C=C_l+C_a$.

In the paper[22], "Distribution of Earthquakes in Japan", the values of E_a and C_a were calculated with certain assumption and C_aE_a-*diagrams* drawn as shown in Fig. 6.

The results show that "deep" earthquakes as well as "conspicuous and rather conspicuous" earthquakes, show to some extent negative correlations with respect to cyclones, while on the contrary, "felt" earthquakes show positive correlation.

As to the physical meaning of these results, I may suggest the following:–

a) The excessive stress stored in the relatively shallow parts of the earth's crust may be released by frequent occurrences of earthquakes of the magnitude of "felt" earthquakes, which are affected directly by the cyclones that frequent the region.

b) When the excessive stress released as the result of "felt" earthquakes is comparatively small in amount, then earthquakes of the magnitudes of "conspicuous and rather conspicuous" and "deep"

22) *loc. cit.*, 19).

earthquakes will occur.

Since then I have made further investigations on the relation between cyclone and earthquake.

The distances to the epicentres of "deep" earthquakes from the nearest cyclonic centres at the time of occurrences of the earthquakes were estimated and counts made of the frequencies coming within every 200 kilometres.

To eliminate the areal effect as well as the characteristic geographical distributions of cyclonic tracks regardless of earthquakes, the frequencies of the total cyclones, 3500 in number, during a period of exactly 8 years from 1926 to 1933, falling on the same zonal areas between concentric circles with "centre of gravity" of the "deep" earthquakes near the coast of Siduoka as origin, were counted. The value of the ratios r, of the actual frequency f_a to the total frequnency f_t, that is $r_1=f_a/f_t$, were calculated and plotted as ordinates, the distances in kilometres being taken as abscissa as shown in Fig. 1 (a), in the paper[23]—"Relation between Cyclone and Earthquake".

From this curve it will be seen at a glance that very near the cyclonic centres, that is, within 200 kilometers from them, "deep" earthquakes very rarely occur, while a marked maximum of frequency seems to exist about 900 kilometers distant from the cyclonic centres.

This latter result seems to suggest that the region of maximum stress difference in the earth's crust due to cyclones occurs at points about 900 kilometers distant from the cyclonic centre.

To test, on the other hand, if the results have any real physical meaning or not with respect to the relation between "deep" earthquakes and cyclones, an artificial case was investigated, in which the positions of epicentres and cyclonic centres were obtained at random by drawing 270 lots. With the artificial epicentres, not corresponding to the cyclones actually, a similar frequency in distances f_b was obtained and the value of the ratio $r_2=f_a/f_b$ calculated and drawn as shown in Fig. 1, (b).

The latter curve for r_2 showed a character similar to that of the former r_1. These results therefore seem to suggest that there is some real physical meaning with respect to the relation between "deep" earthquakes and cyclones.

Next, a quite similar method was used for "conspicuous and rather conspicuous" earthquakes. In this case, however, the epicentres are distributed over a wide area along the Japanese Islands, compared with the former case with a limited area, the so-called "deep" earthquake zones. Consequently, the value of the ratio $r_3=f'_a/f'_t$, shows

23) S. YAMAGUTI, *Bull. Earthq. Res. Inst.*, **12** (1934), 742.

features of purely accidental occurrence as shown in Fig. 2, (*a*), the centre of gravity of the epicentres being taken at a point in the offing near Iwaki. Thus, using the function $f_x=2(n+1-x)$, already given in another paper[24], the percentage value of $r_4=f_x/\sum f_x$ was calculated and drawn as shown in Fig. 2, (*a*). The deviation of r_3 from this value of r_4, *i.e.*, $\Delta r=r_3-r_4$, was obtained and shown in Fig. 2, (*b*). On the other hand the value of the ratio $r_5=f'_a/f'_b$ was calculated and plotted as shown in Fig. 2, (*c*).

The two curves in Fig. 2, (*b*) and (*c*) show similar characters as they do in the case of "deep" earthquakes, except that a rather marked maximum of frequency occurs at a distance of about 500 kilometres in this case, instead of 900 kilometres in the preceding one.

The same results may also be seen from the maps showing the distributions of values of the ratios $r_{10}=N_a/N_t$ and $r_{11}=N'_a/N_t$ as shown in Fig. 5 and 6, in which N_a is the number of cyclones at the time of occurrence of the earthquakes during a period of 8 years from 1926 to 1933 and which fall in a mesh formed by dividing the wide area, each mesh differing from one another by 5° of latitude and 5° of longitude, N_t being its corresponding value for total cyclones at noon in latitude 135°E for every day during the same period of 8 years.

To see under what type of configuration of cyclones and anticyclones surrounding the epicentre, earthquakes are most liable to occur, the following procedure was adopted: All possible distributions of low and high pressure regions were classified into five types as shown in Fig. 11, and the actual number of occurrences of earthquakes M_a belonging each type was counted from weather charts for the days on which the earthquakes actually occurred. The number of arbitrary earthquakes M_b corresponding to M_a was similarly counted from weather charts for days on which no earthquakes occurred, the positions of the artificial epicentres being substituted for the actual ones by drawing a lot successively.

The ratios $r_{14}=M_a/M_b$ and $r_{15}=M'_a/M'_b$ were evaluated respectively for "deep" and "conspicuous and rather conspicuous" earthquakes as shown in the annexed table in the same paper, page 751.

From this table we may say that "deep" as well as "conspicuous and rather conspicuous" earthquakes occur most frequently in such arrangements of low and high pressures as represented by II–type, and further that they are also liable to occur in such a distribution as I–type.

The foregoing results may be regarded as free from accidental occurrences of earthquakes in connexion with the cyclones owing to the

24) S. YAMAGUTI, *Bull. Earthq. Res. Inst.*, **12** (1934), 214.

particular method of investigation as already explained.

As to the physical meaning of these results, we may say that earthquakes are liable to occur when the stress difference in the earth's crust due to cyclones or barometric pressure difference is maximum.

It might also be supposed that the equilibrium of forces acting on the earth's crust may break down with tidal load as the result of abnormal rise of sea level owing to waves probably generated in the region near the cyclonic centre, as already mentioned in another paper[25], "On the Effect of Cyclone upon Sea Level".

In conclusion, I wish to express my heartiest thanks to Prof. M. Ishimoto for his guidance in the course of these studies and his many useful suggestions.

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36. 地震現象の統計的研究の成果に關する檢討

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地震回數の統計的研究に對する檢討が最近喧しく叫ばれる樣になつた．卽ち石本博士の「地震の偶發性」さ題する研究や，松澤博士の「大地震前後の三陸沖の地震活動及び一般に大地震の餘震に就いて」さ題する論文等が發表され，統計的研究に對する注意を喚起された．

著者は昭和5年以來爲したる統計的研究の成果に關し，再檢討を試み且つ出來るだけの註解を附け加へ度いさ思ふ．

其の前に A. Schuster の地震の週期性に關する論文の結果の一部分を，紹介致すこさゝする．

卽ち地震回數の最大なる時期が，數箇の場所に就いて略一致するか又は同一場所に於いても異つた樣々の期間に就いて，類似の形勢を示すならば假令曲線の振幅の計算値が豫想値よりも小であつても，週期が存在するさ云ふこさを證明して居る．其の一例さして第1圖に示される通り1865年より1884年に至る約20年間にオーストリヤに起つた461の地震，ハンガリー，クロアシア及びトランシルバニアに起つた384の地震及びスキス，チロル地方に起つた524の地震を採つた場合の各月の頻度曲線は，よく，一月頃に於いて，3曲線共最大を示して居るこさは週期の實在するこさを證明して居る．

1. 地震さ潮汐さの關係に就いて著者は，關東，丹後，但馬及び大町の4箇所の大地震の餘震を採り，横須賀又は輪島の潮汐さの關係を調べて見たのであるが，4箇所共低潮時附近に於いて地震回數の最大を與へて居るこさ及び樣々の期間に於いても略同樣の結果を與へて居るこさは確かに物理的關係の實在を示すものさ思はれる．

   松澤博士が伊豆地震の餘震に就いて研究された結果に依るさ地震さ潮汐さの關係が，偶然起り得るものさしても0·214位の確率の値が出るさ云ふこさである．

   私の場合に於ける一時間の内の地震の平均數を1さし1+0·214さ1--0·214さの間の範圍を考へて見るさ低潮時附近の地震の數は，前述の4地方共此の範圍より大なるこさを示して居る．

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25) S. YAMAGUTI, *Bull. Earthq. Res. Inst.*, 7 (1929), 115.

又太陽時に對する地震回數の分布を見ると大町地震を除いては，いづれも皆潮位に對するものよりも，其の振幅が小であると云ふことは，卽ち地震發生に對して潮汐の影響が如何に明瞭であるかを示すものと思はれる．

大町は他の3地方に比較して，海より遠方にある爲め大氣壓の日變化の影響らしきものが現はれ太陽時及び潮位に對する振幅が略同程度となつて居るのは當然である．

潮汐の影響の物理的意義を考へて見ると，地殼に或る荷重を及ぼし中等水位附近に於いて，地殼內の應力が釣合にあるものとすれば，低潮時の時は荷重を減ずることゝなるから，其の時に地殼の破壞が起り，從つて地震が發生するものと考へられる．

之は石本博士の研究にかゝる「丹後大地震後の宮津町及び河邊村に於ける地表傾斜變化觀測」の結果より見るも，亦石本博士，高橋學士共著「伊東地震と地表傾斜變化の觀測」並びに高橋學士の「油壺灣內の海水の副振動に因る地殼の傾斜運動」等の研究の結果に徵するも，上述の說明を支持するものと考へられる．

2. 震源移動の問題に關して，實際に移動した數 N_0 と理論上豫期される數 N' との比，$r=N_0/N'$ の値を計算したのであるが，r の値が 1·45 以上及び 0·6 以下のものは眞の物理的意義を有するものと考へることが出來る樣に思はれる．

地震の週期性を研究する目的を以つて世界地震の內 1900 年より 1931 年に至る 31 年間に起つた 420 ものに就いて，時間の間隔が，次々の10日毎の內に這入る樣な地震の回數曲線を見ると一般の形勢は偶發性を示して居る．故に今之を $f=ae^{-bt}$ で表はされるものとして計算し之を實際に起る回數より差引いて其の殘りのものを畫いて見ると，27·5 日，55 日及び 105 日と云ふ週期が見られる．而して全體の地震に就いても，亦此の內特別なもの，卽ち震源が引續いて起り易いもの，$N=118$, $r>1·25$ に就いても又更に，$N=78$, $r>1·6$ のものに就いても上述の週期が見られると云ふことは決して偶然の出來事では無いと信ずる．

日本に於ける深層地震に就いても之と全く同樣の週期を有する事は誠に面白いことゝ思ふ．此の週期は地球に對する太陽の自轉の週期 27·3 日及び其の倍數に相當する．米國のウエルスン天文臺及び英國のグリニッチ天文臺の調查に因ると，この週期を以つて太陽面に水素瓦斯の大爆發が起つて居ることが明らかにされて居る．之に關聯して太陽より地球に及ぼす何等かの力に，かゝる週期的變化を與ふるのではなからうかと云ふ疑問を起さしめるのである．

3. 低氣壓或は氣壓分布と地震との關係に就いて豫備的研究を試みた結果，之等の間には，密接な關係のあることが分つて居る．而して有感地震と低氣壓とは正の相關係數を有し，深層地震或は顯著及稍顯著地震と低氣壓との間には負の相關係數を有する．

其の後更に詳細なる研究を試みた結果は，深層地震に就いては，低氣壓の中心より900粁の地點に於いて又顯著及稍顯著地震に就いては500粁位の距離の場所に於いて，地震が最も起り易いことを示して居る．之は偶發性を考慮に入れてそれを消去して居るから眞の物理的關係を有するものと考へられる．

以上の結果に就いては，低氣壓に因り，又一般には氣壓分布に因つて，地殼の中に生ずる應力の差異が最大になる樣な時に地震が發生し易いものと推定される．或は又低氣壓が現はれるときは，低氣壓の中心附近に於いて發生する波浪に因つて近海面が異常上昇を來す爲めに地殼に餘分の荷重を與へてその結果地殼の釣合を破るやうになるのではなからうかと想像される