5. *On Time and Space Distribution of Earthquakes.*

By Seiti YAMAGUTI.

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1. Introduction.

It was already remarked by the seismologists of our country, that the seismic activities in different districts seem to be connected by some statistical law of sequence, that is, the earthquakes are liab'e to occur in some particular regions immediately following an earthquake in a certain region.

The present investigation was made with the intention of testing this opinion statistically and also of studying the relation between the direction of the apparent "movement"[1] or "transfer" of epicentre and the barometric gradients as well as the other meteorological elements.

It was hoped also that we may obtain by this investigation some hint on the existence and location of the "weak lines" of the earth's crust in our country.

The investigation was made with regard to the earthquakes in the different parts of Japan as well as of the entire world.

The statistical frequencies of time intervals of the successive earthquakes were also investigated and thus the probable "periods" of occurrence were obtained.

2. Methods of Investigations.

1) Kwantô Districts.

From the Abridged Monthly Report of the Central Meteorological Observatory in Japan, the "felt" earthquakes, 2370 in number, were taken, which occurred in Kwantô Districts (Provinces of Iwaki, Suruga, Kai, and a southern part of Sinano included), during the period of 7 years, June, 1924—May, 1931. The epicentres[2] were plotted on a map

1) For convenience's sake, the epicentre is supposed to move from one spot to another to cause the successive earthquakes.

2) The position could only roughly be estimated as the name of the district is only known.

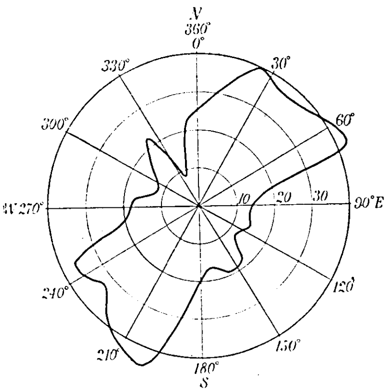

Fig. 1, *a*. Spring.

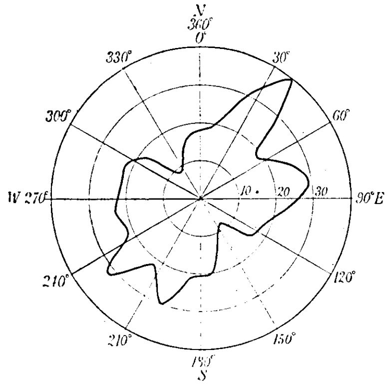

Fig. 1, *b*. Summer.

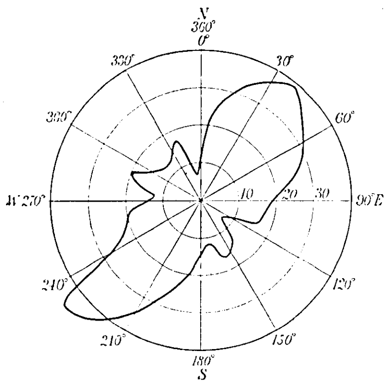

Fig. 1, *c*. Autumn.

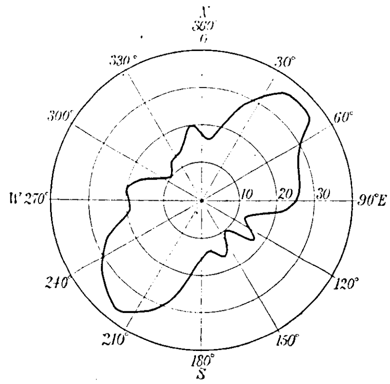

Fig. 1, *d*. Winter.

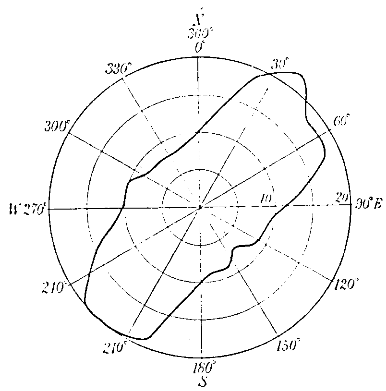

Fig. 1, *e*. Yearly Mean.

for each month and connected by a straight line successively in the order of time. The number, n, of these straight lines, falling in the direction within each sector of azimuth angle 15°, which is formed by dividing all directions into 24 parts, were counted. The number, n, thus obtained were separated into 4 groups, according to the seasons, i.e., Spring (March—May), Summer (June—Aug.), Autumn (Sept.—Nov.), and Winter (Dec.—Feb.), and they were plotted in vector diagrams against the azimuth angle, N-direction being taken as zero, as shown in Fig. 1. The yearly mean diagram for all seasons of 7 years is shown in Fig. 1, *e*.

For 120 "conspicuous" and "rather conspicuous" earthquakes, which occurred in the same districts, during the same period, the azimuthal distribution of the direction of epicentre "transfer" were investigated and plotted in the similar manner, as shown in Fig. 2. In this case, the positions of epicentres are more distinctly known than the former case.

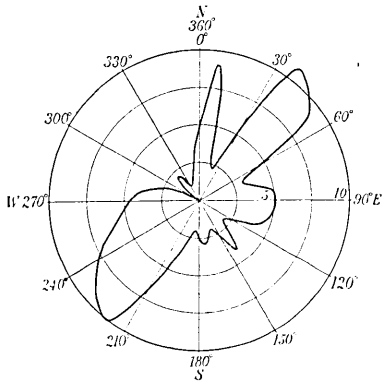

Fig. 2. "Conspicuous" and "rather conspicuous" earthquakes.

Vector diagrams were also drawn which show the characteristics of given districts in the mode of sequence of earthquakes, giving the azimuthal distributions of epicentres of the earthquakes which occurred immediately

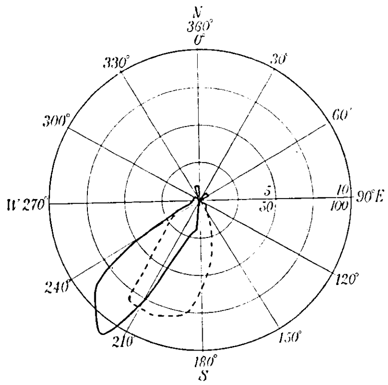

Fig. 3, *a*. Before and After an earthquake at Iwaki.
——"conspicuous" and "rather conspicuous" earthquake.
------"felt" earthquakes.

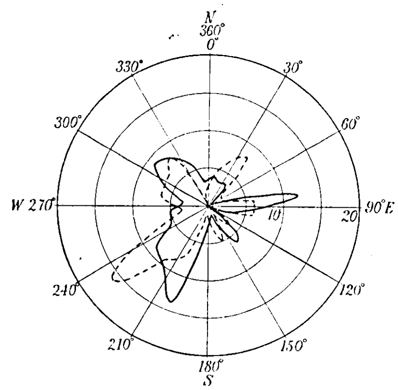

Fig. 3, *b*. "Felt" earthquakes. Kasumigaura.
—— Before
------ After

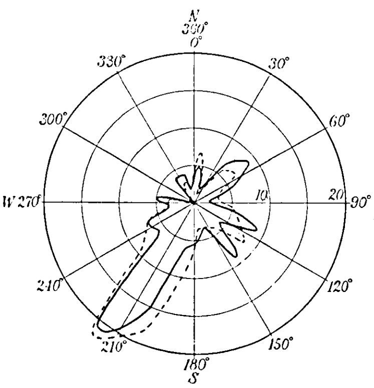

Fig. 3, *c*. "Felt" earthquakes.
Tukuba.
—— Before
------ After

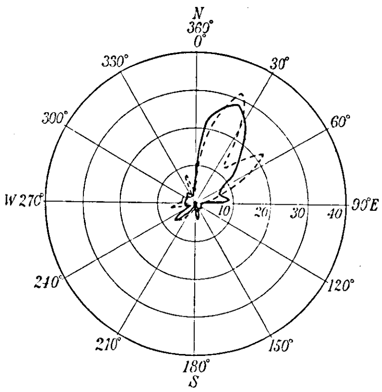

Fig. 3, *d*. "Felt" earthquakes.
Tôkyô.
—— After
------ Before

before and after an earthquake in a definite locality, as shown in Fig. 3.

To get a hint of the physical meanings of transfers of epicentres in such directions as shown in the above figures, the number, n, were separated into 12 groups for 12 months, and compared with the directions of pressure gradients at Iwaki, using the results of investigation "On the Relation between the Frequencies of Earthquakes and the Pressure Gradients", by Prof. T. Terada.[3]

The vector diagram for n's were transformed into the corresponding xy-diagrams and arranged as in Fig. 4, *a*, taking the directions of the monthly mean pressure gradients at Iwaki as the respective origins of directions, the error of $\pm 7.°5$ being admitted. The similar xy-diagrams are also constructed for the deviations of n from the yearly mean. The results are shown in Fig. 4, *b*, *c*, in which dotted lines on the left-hand quarter are the means of the four quadrants.

Before we may inquire into the physical meaning of the above result, it is necessary to make a calculation regarding the statistical probability of n for the case in which the earthquakes occur quite at random. For this purpose, the whole region were divided into 13 districts according to the usual classification made by the Central Meteorological Observatory, and the following calculation of probability was made.

Let N_K, N_L, ... be the number of earthquakes which occurred at

3) *Journ. Meteorolog. Soc.*, Japan, 28 (1909).

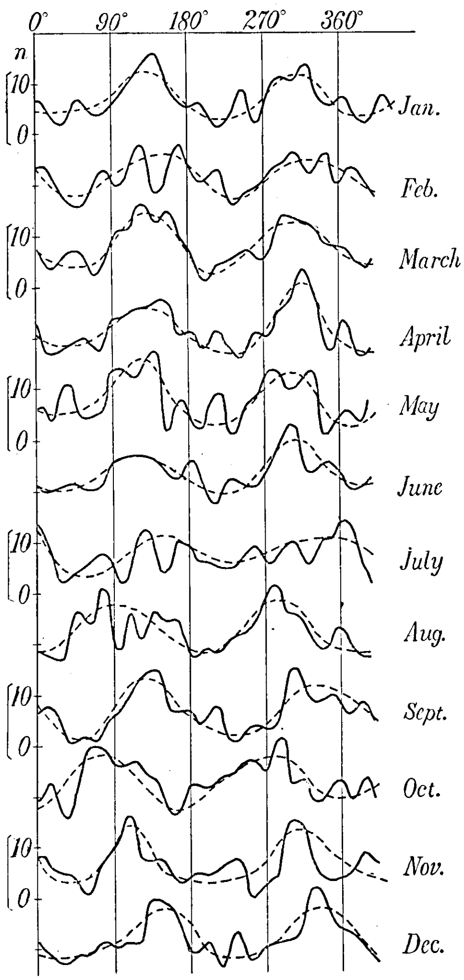

Fig. 4, *a*. *xy*-diagrams for *n*'s, with the directions of the monthly mean presure gredients at Iwaki as the respective origins of directions.

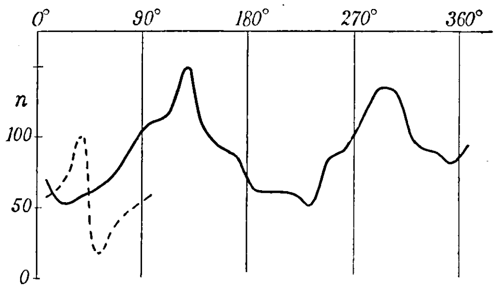

Fig. 4, *b*. Yearly Sum. Broken line shows the mean of the four quadrants.

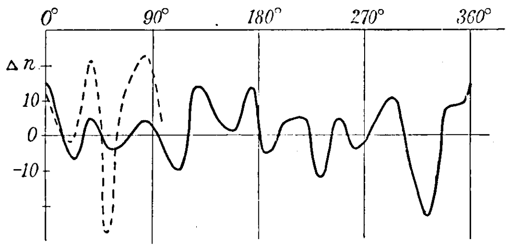

Fig. 4, *c*. Deviation from the yearly mean.

the districts, K, L, ...respectively during the epoch taken, then the probability, P_{KL}, that the earthquakes will occur at the district L, next to K, may be expressed by $P_{KL}=\frac{N_K N_L}{\Sigma\Sigma N_K N_L}$, and the expected number, N', to occur at L, next to K, will be given by $N'=P_{KL}\Sigma N$, where $\Sigma N=2370$. The value of the ratio, r, of the actual number of occurrences, N_0, to the calculated number, N', that is $r=\frac{N_0}{N'}$, were calculated as shown in Table I.

Table I. Kwantô District.

$r>1{\cdot}3$ and $r<0{\cdot}6$ are distinguished by different types respectively.

1. Iwaki,
2. Kasimanada,
3. Kasumigaura,
4. Tukuba,
5. Kinugawa,
6. Kuzyûkuri-Oki,
7. Bôsô Hantô,
8. Tôkyô,
9. Simotuke-Koduke,
10. Sagami Wan,
11. Sagami (land),
12. Suruga-Kai,
13. Idu Hantô.

After / Before	1	2	3	4	5	6	7	8	9	10	11	12	13
1	**2·1**	0·91	1·1	0·87	0·97	1·1	0·75	*0·56*	1·0	0·85	1·1	0·65	**1·3**
2	1·0	**1·3**	1·1	0·78	0·92	0·76	0·85	0·96	1·1	1·1	0·87	1·2	0·92
3	1·1	1·2	1·0	1·1	1·2	0·71	1·0	0·63	0·93	0·69	1·1	1·05	1·01
4	0·80	0·72	**1·8**	0·92	0·83	*0·28*	0·77	1·2	**1·7**	1·03	1·1	*0·59*	**1·4**
5	0·87	1·2	0·84	**1·5**	1·2	0·77	0·81	1·1	1·0	0·80	0·64	0·94	*0·59*
6	0·71	1·1	0·64	0·93	0·73	**3·2**	*0·42*	0·77	0·67	**1·6**	**1·3**	0·64	0·95
7	0·87	*0·55*	1·0	0·92	0·85	**1·3**	**2·4**	1·0	1·0	1·1	0·84	*0·43*	0·80
8	1·1	0·96	**1·5**	*0·50*	1·0	0·77	0·87	**1·6**	0·93	0·67	0·86	1·1	*0·50*
9	1·0	1·1	1·1	0·79	**1·4**	*0·47*	0 57	0·79	**2·0**	*0·52*	0·91	1·2	*0·37*
10	0·77	0·93	0·69	0·72	0·75	**1·4**	1·2	1·0	0·72	**4·0**	*0·18*	*0·56*	*0·43*
11	0·93	0·77	1·0	1·2	0·71	0·65	0·71	**1·4**	0·61	*0·53*	**2·4**	**2·6**	0·85
12	*0·56*	1·0	*0·35*	**1·8**	1·1	0·64	**1·4**	0·77	*0·48*	*0·56*	**2·3**	**2·1**	1·2
13	**1·3**	0·77	0·64	0·74	0·82	0·81	0·91	**1·3**	*0·37*	*0·43*	0·64	1·02	**4·4**

The particular pairs of districts which correspond to values of r greater than 1·3, and those less than 0·6, were respectively taken and shown on the maps of Fig. 5, *a*, *b*. The arrows show the order of sequence of earthquakes. Two arrows connecting a pair of districts in opposite senses show that between these two districts the either sense of transfer is probable in Fig. 5, *a*, and improbable in Fig. 5, *b*. A single arrow shows that the transfer in that sense only is so.

Similarly, such pairs of "conspicuous" and "rather conspicuous" earthquakes with $r>1{\cdot}5$ and $r<0{\cdot}45$, is shown in Fig. 5, *c*.

Taking the directions of the straight lines, connecting all the possible pairs of the centres of these 13 districts, the vector diagrams for the mean of r in each azimuth, were constructed as shown in Fig. 6.

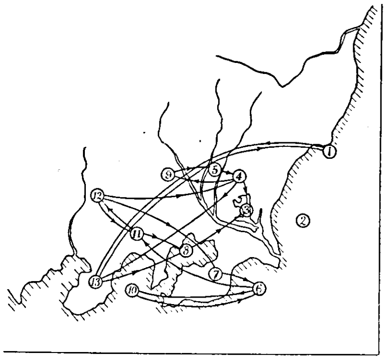

Fig. 5, *a*. Pairs of regions with $r>1{\cdot}3$

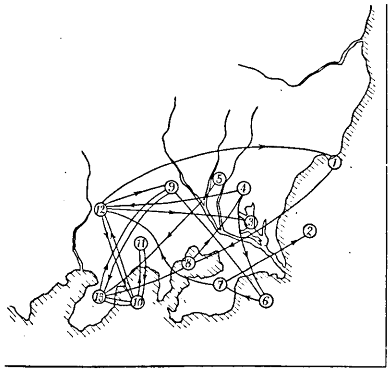

Fig. 5, *b*. Pairs of regions with $r<0{\cdot}6$

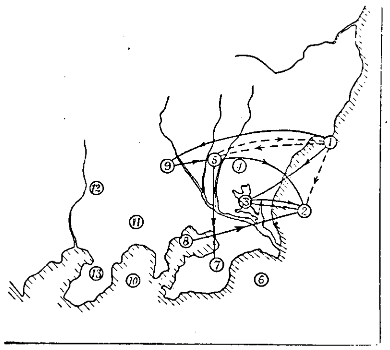

Fig. 5, *c*. "Conspicuous" and "rather conspicuous" earthquakes.

⟶ $r>1{\cdot}5$ ‑‑‑→ $r<0{\cdot}45$

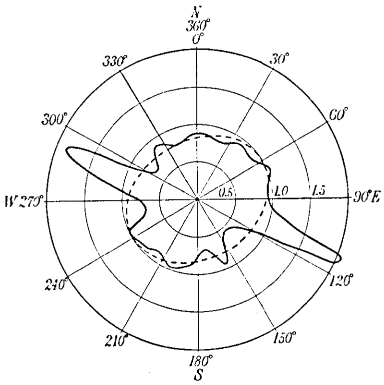

Fig. 6, *a*. Azimuthal mean of r's for all possible combinations.

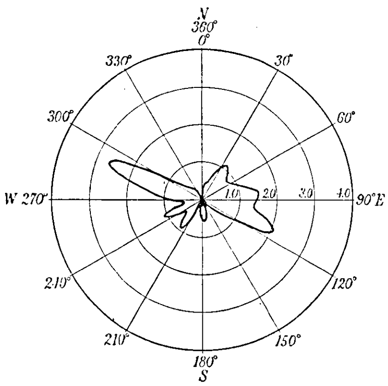

Fig. 6, *b*. Azimuthal means of r's taken for those combinations with $r>1{\cdot}3$ and $r<0{\cdot}6$, excluding the cases $1{\cdot}3>r>0{\cdot}6$.

2) Tôhoku and Hokkaidô.

The "felt" earthquakes, 1410 in number, which occurred during the same period as in the case of Kwantô District above investigated, were taken and similarly treated. In this case, however, the directions of transfer of epicentres were comparatively simple, and seemed to be conveniently separated into two kinds, one of which is N–S direction, and the other E–W direction approximately. For the first kind, we have divided the entire regions into 8 groups according to latitudes i.e., 37°–38°, 38°–39°, ... 43°–44°, and 44°–46°, and calculated the values of $r=\frac{N_0}{N'}$, for each pair of groups, which are shown in Table II.

Table II. Tôhoku and Hokkaidô

1. Near Iwaki	(37°–38°*N*)	5. Near Mutu Oki (41–42°*N*)
2. „ Kinkwazan	(38–39)	6. „ Hokkaidô, S. part (42–43)
3. „ Miyako	(39–40)	7. „ „ , mid. (43–44)
4. „ Mabutigawa	(40–41)	8. „ „ , N. (44–46)

Before \ After	1	2	3	4	5	6	7	8
1	**1·4**	**1·4**	0·84	0·86	0·70	0·76	1·0	0·78
2	1·1	1·02	1·1	*0*	0·80	1·0	1·1	1·03
3	0·92	0·65	**1·4**	**1·4**	0·66	0·79	1·15	**1·3**
4	*0·47*	*0*	**1·4**	**5·4**	0·97	**1·3**	*0·58*	*0*
5	0·87	1·2	*0·50*	0·65	**2·1**	0·89	1·04	0·79
6	0·95	0·80	0·97	*0·53*	0·93	**1·6**	0·78	1·16
7	0·84	1·17	1·1	0·77	1·1	0·84	1·2	*0·53*
8	**1·3**	*0*	0·87	**1·9**	**1·3**	1·0	*0·32*	**5·2**

For the second kind of epicentre transfer, we have counted the number, *J*, of the transfer of epicentres in E→W or W→E direction, remaining in nearly the same latitude, for every month of 7 years, and investigated, in which month the value of *J* is relatively great. On the other hand, the corresponding monthly barometric pressure gradients towards north and towards east, were calculated from the data for Sapporo, Isinomaki, Nemuro, and Niigata, respectively, and compared with *J*. No sensible correlation could be found between them. Next, the number of tracks of cyclones for every month traversing these regions were taken from the Abridged Monthly Report of the Central Meteorological Observatory in Japan, and compared with J in the following manner.

The values of J and the number of tracks of cyclones were respectively plotted side by side against the same time axis. A certain tendency of parallelism is observed between two curves.[4]

Taking J and the number of tracks as ordinate and abscissa respectively, xy-diagram was plotted (Fig. 7, a). We have imagined that some better correlation may be revealed between J and number of cyclones, if we take J in the limitted region near Hokkaidô, with greater latitude than 42°, and a corresponding diagram was also drawn for this region alone (Fig. 7, b).

Taking, instead of J, the ratio, r', of J to the total number of earthquakes, N, for each month which occurred in the whole region, an xy-diagram was similarly drawn (Fig. 7, c). In these diagrams, curved lines are constructed by connecting the mean point of each y corresponding to each x, and the ellipse in the last diagram is drawn by inspection so as to contain all points properly.

For the last diagram, the similar method of analysis was applied as explained in the previous paper[5], and obtained the percentage values of $a=43$, $b=25$, $c=28$, $d=4$, showing a predominance of positive correlation.

We have also calculated the correlation cœfficient, c, of r' with respect to the number of tracks of cyclones, applying the ordinary

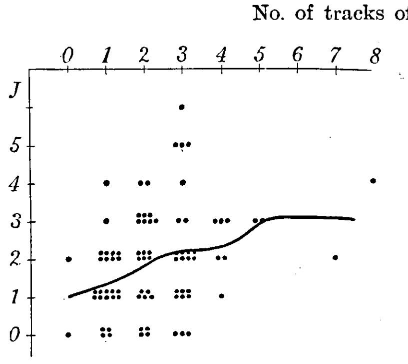

Fig. 7, a. Whole region (37°–46°N).

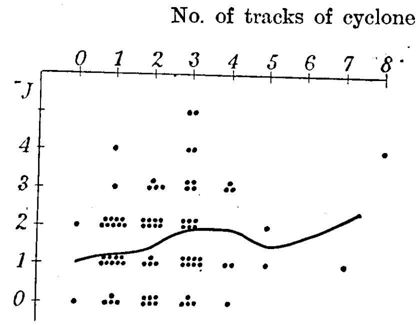

Fig. 7, b. Near Hokkaidô (>42°N).

4) Curves here omitted.

5) S. YAMAGUTI, *Bull. Earthq. Res. Inst.*, 10 (1932), 36.

formula, $c=\dfrac{\Sigma\xi_k\eta_k}{\sqrt{\sum\limits_k\xi_k^2\sum\limits_k\eta_k^2}}$, where $k=1,2,$ .... 84, and obtained 0.47 for its value. The results may suggest the possible existence of such an effect of cyclone.

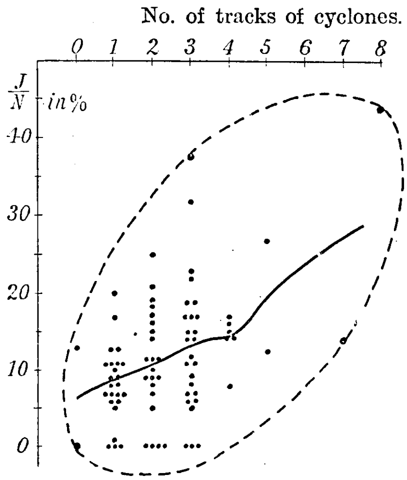

Fig. 7, c. Whole region.

3) All Parts in Japan.

a) The "conspicuous" and "rather conspicuous" earthquakes, 370 in number, which occurred in Japan, during the period of 7 years (June, 1924—May, 1931), were taken from the Abridged Monthly Report and investigated with regard to their mode of sequence from one group of latitude to another, in the similar manner as before. Corea was excluded for obvious reason.

Table III, *a*. "Conspicuous" and "rather conspicuous" earthquakes in Japan taken from Kisyô Yôran.

1. 22°–26°*N* 3. 32°–34°*N* 5. 35°–36°*N* 7. 37°–38°*N* 9. 40°–42°*N*
2. 26–32 4. 34–35 6. 36–37 8. 38–40 10. 42–45

Before \ After	1	2	3	4	5	6	7	8	9	10
1	**3·3**	0	0·91	0·53	0·81	0·98	*0*	0·59	0·57	**2·1**
2	0	0	0	**2·5**	0·62	*0·38*	0	**2·8**	**2·0**	**1·7**
3	**1·4**	1·1	1·2	0·87	0·91	1·0	1·0	1·0	**1·4**	0·29
4	1·05	1·25	0·87	**2·5**	0·77	0·94	*0·38*	1·1	0·83	1·03
5	1·1	0·62	*0·45*	1·02	**2·4**	*0·58*	1·2	*0·29*	**1·4**	*0·18*
6	0·78	0·95	1·2	*0·38*	0·68	**1·6**	**1·6**	*0·21*	*0·52*	**1·3**
7	0·80	**1·8**	1·0	1·15	**1·4**	**1·3**	0·86	**1·3**	*0·20*	0·77
8	*0*	**1·4**	1·0	*0*	1·2	0·85	**2·6**	**3·1**	*0·31*	*0·38*
9	*0·57*	**1·3**	**1·4**	**1·4**	*0·56*	*0·52*	*0·41*	*0·31*	**2·4**	**1·3**
10	1·1	0·83	1·2	0·69	*0·35*	1·02	**1·3**	**2·3**	*0·56*	**1·4**

b) The "destructive" earthquakes, 315 in number, which occured

Table III, b. "Destructive" earthquakes in Japan taken from Rikwa-Nenpyô.

1. Tyôsen.
2. Taiwan
3. Kyûsyû
4. Sikoku-Tyûgoku
5. Kinki
6. Nôbi-Hokuroku
7. Kwantô
8. Tôhoku (37°–40°N)
9. Mutu-Hokkaidô

Before \ After	1	2	3	4	5	6	7	8	9
1	**2·9**	*0·26*	0·61	0·42	0·84	*0·22*	1·1	0·88	*0·35*
2	0	**2·9**	0·95	**2·7**	0·68	1·1	0·91	*0·56*	1·1
3	0·91	1·4	**3·3**	1·5	0·79	0·83	*0·21*	0·67	1·2
4	*0·42*	1·33	1·5	**2·2**	*0·37*	**2·4**	*0·59*	0·45	**1·8**
5	0·99	*0*	1·05	*0*	**2·6**	0·99	0·79	0·77	*0·3*
6	*0·44*	**1·8**	0·83	0·59	0·59	**2·5**	0·95	1·2	*0*
7	0·67	0·73	0·83	**2·1**	0·79	*0·48*	**1·4**	1·1	1·2
8	1·05	1·1	0·67	*0*	0·77	0·73	0·99	**1·7**	**1·5**
9	*0·35*	1·1	0·62	0	0·3	**1·4**	**1·4**	1·1	**2·9**

in Japan during the period from 27 A.D. to 1931, were taken from Rikwa-Nenpyô (the Scientific chronological Table), and similarly treated as before. In this latter case, however, all regions were divided into 9 parts, those are, Tyôsen, Taiwan, Kyûsyû, Sikoku-Tyûgoku, Kinki, Nôbi-Hokuroku, Kwantô, Tôhoku, and Mutu-Hokkaidô.

The results for these two cases are shown in Table III, *a*, *b*.

Among such cases with $r<0{\cdot}6$, those, which have too small expected number, N′, are to be disregarded in discussions of the results.

4) All Parts of the World.

The Great Earthquakes, 420 in number, which occurred in different parts of the world, during the period of 31 years, 1900—1931, were taken from Rikwa-Nenpyô, and they were classified into 8 groups according to the geographical regions of occurrence: those are, the Coast of the Mediterranean Sea, Continent of Asia, Japan, the Philippines with neighbouring oceanic regions, Australia including the oceanic environments, North America, Central America, and South America, and similarly treated as before. The results are shown in Table 4, *a*, and in Fig. 8, *a*, *b*. In this case, the probability, P, that the earthquakes will occur at any three regions J, K, L, successively, was also calculated by $P=\frac{N_J N_K N_L}{\sum\limits_J \sum\limits_K \sum\limits_L N_J N_K N_L}$ and the expected number, $N'=P\Sigma N$, and the values of the ratio, $r=\frac{N_0}{N'}$, were calculated for about three hundred combinations. The particular combinations of 3 regions which correspond to $r>4$, $4>r>3$, and $3>r>2$, where $N_0>3$, were taken out as shown in following Table IV, *b*.

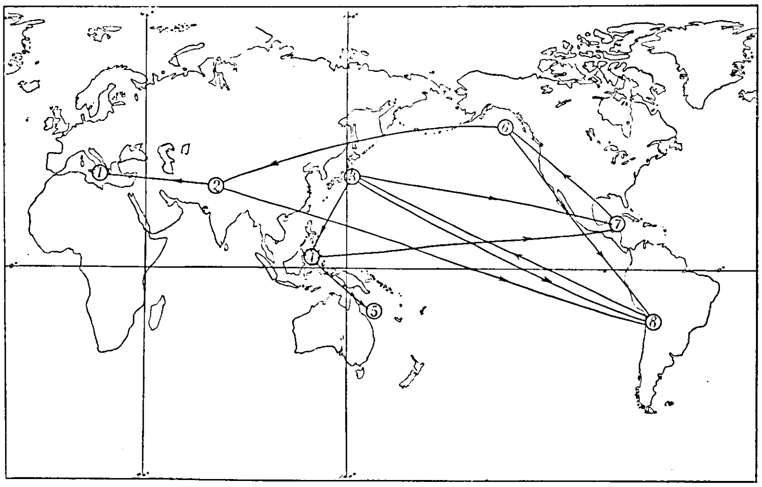

Fig 8, *a*. Pairs of earthguakes with $r>1{\cdot}25$.

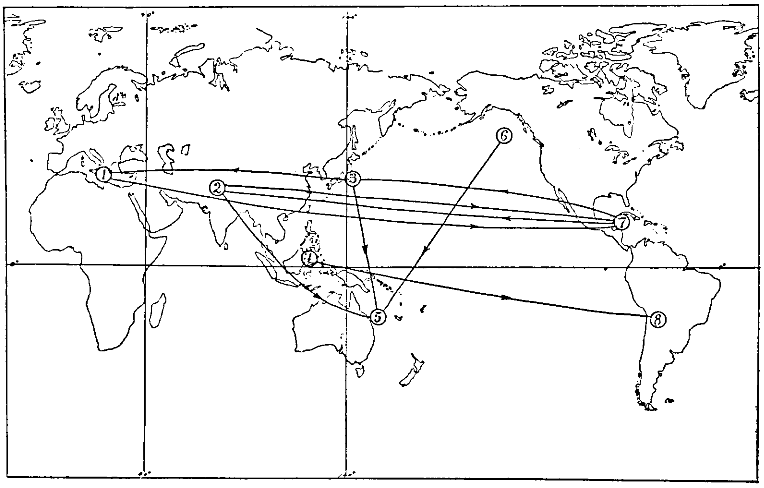

Fig 8, *b*. Pairs of earthquakes with $r<0{\cdot}6$.

Table IV, *a*. All Parts of the World.

After / Before	1	2	3	4	5	6	7	8
1	**1·8**	9·4	1·03	1·2	1·2	*0·37*	*0·16*	0·73
2	**1·3**	**2·34**	1·2	0·63	*0·53*	0·85	*0·37*	**1·3**
3	*0·59*	1·0	0·66	**1·65**	*0·53*	*0·33*	**1·3**	**1·64**
4	0·89	0·76	0·83	0·90	**1·6**	1·0	**1·3**	*0·49*
5	0·94	0·8	0·95	1·1	0·92	1·1	1·15	1·05
6	*0·37*	**1·7**	1·0	1·0	*0·54*	**1·7**	1·1	**1·3**
7	1·13	*0·55*	*0·58*	0·77	1·03	**2·2**	**1·6**	0·90
8	0·73	0·625	**1·8**	0·74	1·2	0·83	0·90	1·02

1. The Coast of the Mediterranean Sea. 2. Continent of Asia. 3. Japan. 4. The Philippines with neighbouring oceanic regions. 5. Australia including the oceanic environments. 6. North America. 7. Central America. 8. South America.

Table IV, *b*. All parts of the World.

$r \geqq 4$	$4 > r \geqq 3$	$3 > r \geqq 2$
2 → 1 → 2	1 → 3 → 4	1 → 4 → 4
2 → 2 → 2	2 → 8 → 5	1 → 5 → 7
2 → 2 → 8	3 → 4 → 1	3 → 4 → 8
3 → 8 → 2	4 → 6 → 4	4 → 1 → 1
8 → 3 → 8	4 → 7 → 1	5 → 5 → 5
5 → 4 → 6	5 → 4 → 5	5 → 8 → 7
7 → 7 → 7	5 → 2 → 2	7 → 3 → 4
8 → 1 → 1	8 → 5 → 8	4 → 3 → 7
		7 → 5 → 3
		8 → 3 → 4
		8 → 7 → 5

5) Frequencies of the Time Intervals.

The time intervals from an occurrence of the great earthquakes to the next one, were obtained for the different cases of the above data of the earthquakes, i.e. in the world, in all parts of Japan, and in Kwantô Districts, and the frequencies of intervals falling in successive 10 or 100 days, respectively, were counted and plotted as ordinates, the days of the intervals being taken as abscissa. The general trend of these curves shows the random occurrence of the earthquakes. We have calculated the frequencies, f, for purely random occurrence, assuming, $f=ae^{-bt}$, and obtained the deviations of the actual frequencies from these theoretical values of f, which are shown in Fig. 9, *a*, *b*, for the Great Earthquakes in the World. In order to ensure that the periodicity of the deviation curve is not due to the apparent one proper to any accidental phenomena[6], we have also tried to take the half intervals, or the overlapping intervals of days for comparison. The essential feature of the curves remained the same.

For the particular pairs of the earthquakes, in the above three cases, corresponding to $r>1{\cdot}25$, $r>1{\cdot}4$, $r>1{\cdot}6$, and $r<0{\cdot}6$, which are the results in the previous investigation, the similar treatments were applied.

The curves for the "destructive", "conspicuous" and "rather conspicuous" earthquakes in Japan are shown in Fig. 10, 11, and 12, respectively.

The curve for the "conspicuous" and "rather conspicuous" earthquakes in Kwantô District is shown in Fig. 13.

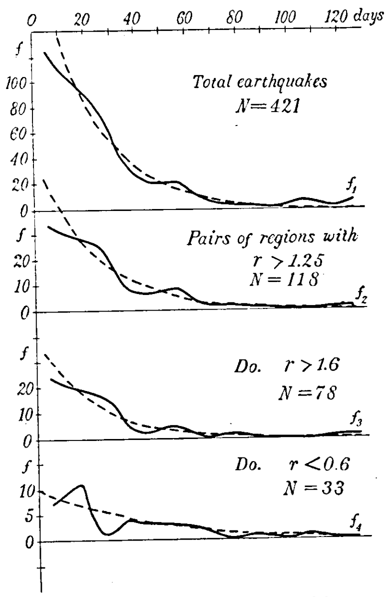

Fig. 9, *a*. In the world.
——actual curve.
·······theoretical curve.

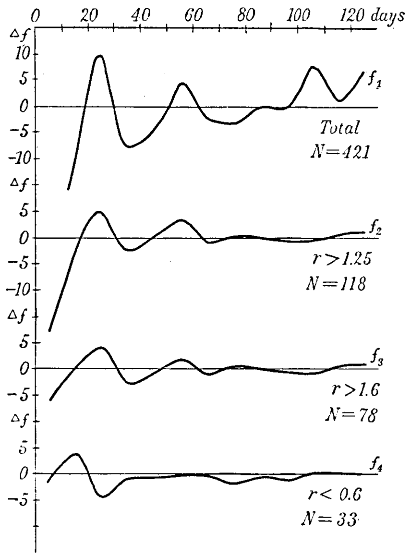

Fig. 9, *b*. In the world.
Deviation curves of frequency.

6) T. TERADA, *Proc. Tôkyô Physico-Math. Soc.*, [2], 8 (1916).

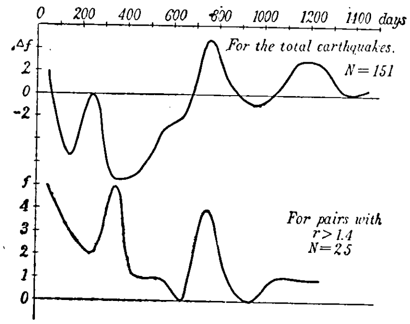

Fig. 10. Japan. "Destructive" earthquakes.

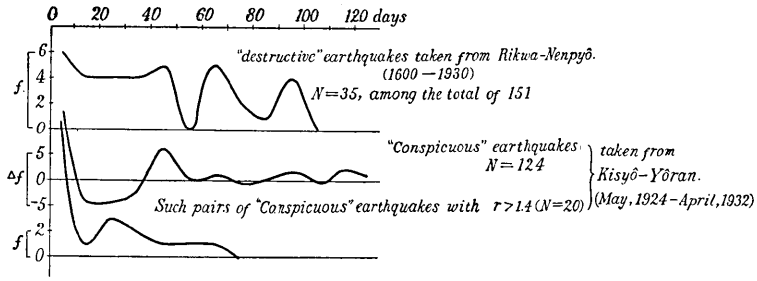

Fig. 11. Japan. "Conspicuous" earthquakes.

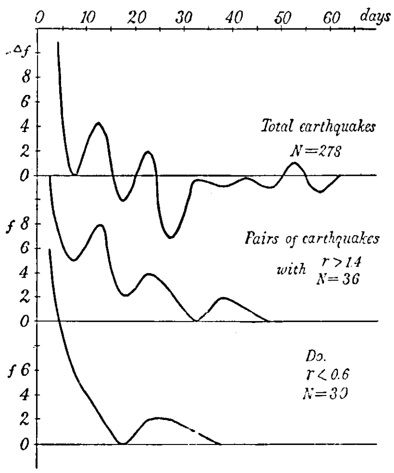

Fig. 12, *a*. Japan. "Rather conspicuous" earthquakes.

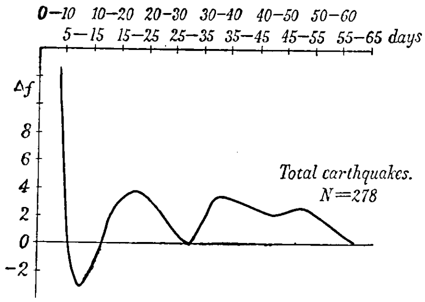

Fig. 12, *b*. Do. Overlapping intervals.

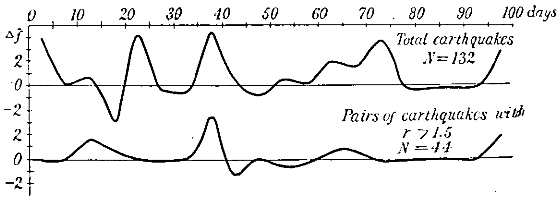

Fig. 13. Kwantô.
"Conspicuous" and "rather conspicuous" earthquakes.

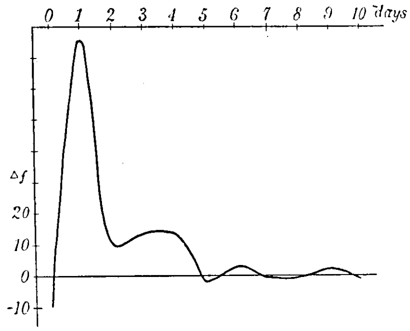

Fig. 14. "Felt" earthquakes in Kwantô Districts (May, 1925—April, 1928) $N=573$

In the case of Kwantô Districts, the similar investigation was made for the "felt" earthquakes also, successive one day intervals being taken here, which result is shown in Fig. 14.

3. Results and Discussions.

1) Kwantô Districts.

From Fig. 1, we can recognize some seasonal variations in the mode of transfers of epicentres, which may probably be connected with the barometric pressure gradients. If we take the annual mean of 7 years, above seasonal variations entirely vanish, and the diagram forms a smoothed ellipse, of which the major axis runs from NE to SW directions. The vector diagram for winter resembles to this yearly mean, which fact might have some physical meanings to be still investigated.

Looking at the curves showing the deviation from the yearly mean, opposite trends are observed between the curves for spring and summer, as well as for autumn and winter.

The diagram (Fig. 2) for the "conspicuous" and "rather conspicuous" earthquakes shows somewhat different features compared with that for "felt" earthquakes, i. e. the protuberances in NE, SW and northward directions are sharply defined.

Referring to Fig. 3, *a*, before and after the earthquakes in the Sea off Iwaki, there is a large probability of finding the "felt" earthquakes in SSW-direction, and the "conspicuous" and "rather conspicuous" earthquakes, in SW-direction.

Many interesting features are observed regarding probabilities of occurrences of the next "felt" earthquakes in different azimuth before and after the earthquakes at different localities (Fig. 3, *a*, *b*, *c*, *d*), of which details will be reserved for a future investigation.

From the vector diagram which corresponds to Fig. 4, it seemed at first glance, as if there exist some maxima at the directions of about zero, 45°, and 90° measured from the direction of pressure gradient. The vector diagrams were transformed into *xy*-diagram to make this fact more apparent, the angle being taken in clockwise sense, as shown in Fig. 4. Form the mean of the four quadrants of the yearly sum curve, given by broken curve, we can see the distinct maximum somewhere near 45°, which may correspond to the direction of maximum shearing stress in the earth crust due to the pressure gradient (Fig. 4, *b*). The yearly sum curve for the deviations from eilipse (yearly mean) above cited, has shown maxima of curve at about 0°, 45°, and 90°. The maxima at 0°, and 90° may mean that a tangential or normal stress upon a preexisting fissure may call forth a succession of earthquakes along that fissure line. It is interesting to observe that the pressure gradient at Tôhoku has given the better results than that at Tôkyô. The comparison of pressure gradient with the "conspicuous" and "rather conspicuous" earthquakes is omitted here, the number of cases being too scanty for this purpose.

From Table I and Fig. 5, *a*, *b*, we may be able to remark as to the "felt" earthquakes, the followings :—

a) The earthquake is most probable to occur once more immediately in the same district when an earthquake occurs in a certain district.

b) The earthquakes are liable to occur at Idu next to Iwaki, and vice versa.

c) The following combinations of districts have large probability of epicentral transfer ($r > 1{\cdot}7$) :
Tukuba → Kasumigaura, Tukuba → Simotuke-Koduke-Nisimusasi, and Suruga-Kai-Minamisinano → Tukuba.

d) Two combinations of districts such as, Tyôsi-Kuzyûkuri-Oki and the Sagami Bay, as well as Sagami (land) and Suruga-Kai-Minamisinano, have large probability of epicentral transfer to and from each other.

e) After an earthquake in Tôkyô and the Tôkyô Bay, Kasumigaura has a large probability of occurrence of the next earthquake, and it is 3 times as large as that at Tukuba, which is situated very near to Kasumigaura, while on the contrary, after the earthquakes in Suruga-

Kai-Minamisinano, Tukuba has 5 times as large probability than Kasumigaura.

f) After an earthquake at Tukuba, the next one occurs very rarely off Kuzyûkuri ($r=0{\cdot}28$).

g) Such combinations as, Off Kuzûykuri→Bôsô Peninsula, Bôsô Peninsula → Suruga-Kai-Minamisinano, and Tukuba → Suruga-Kai-Minamisinano, habe very small probability of epicentral transfers, and they are only one third of those for the reverse directions.

h) Sagami Bay seems to be indifferent toward Sagami (land), Idu, and Suruga-Kai-Minamisinano as for the occurrence of "felt" earthquakes, as well as Idu towards Simotuke-Kôduke-Nisimusasi.

i) If we connect the pairs of districts with large probability of epicentral transfer in due order of succession, we may be able to draw the following two loops :—

Tukuba→Simotuke-Kôduke-Nisimusasi→Kinugawa→Tukuba.

Off Kuzyûkuri→Sagami (land)→Suruga-Kai-Minamisinano→Bôsô Peninsula→Off Kuzyûkuri.

j) Kasimanada earthquakes occur very frequently in succession with an earthquake in different districts both before and after the latter, except only that the earthquakes at Kasimanada very rarely occur next to Bôsô Peninsula.

As for the "conspicuous" and "rather conspicuous" earthquakes, (Fig. 5, *c*) the following tendencies are observed though the total number of earthquakes taken is only 126.

a) Next to a "conspicuous" and "rather conspicuous" earthquake at Iwaki, either Kasumigaura or Simotuke-Kôduke-Nisimusasi is very liable to have such an earthquake, while Kasimanada has little chance to have such one, which results are also to be seen in Fig. 3.

b) Kasimanada has large values of probability of occurrence of such an earthquake immediately after Tôkyô, Kasumigaura, or Kinugawa.

c) Iwaki and Kinugawa are indifferent toward each other, as for the occurrence of earthquakes.

On the diagram of the mean r (Fig. 6, *a*), we can draw an ellipse, major axis of which is inclined about 50° from north. Besides, the graph has conspicuous maxima in the directions WNW and ESE. On the other hand, the azimuthal mean of r's, such as $r>1{\cdot}3$ and $r<0{\cdot}6$, (Fig. 6, *b*), gives somewhat similar diagram as the former.

2) Tôhoku and Hokkaidô.

From Table II, we may be able to remark the followings:—

a) An earthquake in a certain district is liable to be followed by another in the same district.

b) After an earthquake in North Hokkaidô (>44°N), another is liable to occur near Iwaki, but such rarely occurs near Kinkwazan (38°–39°N), in spite of the neighbouring situation.

c) From North Hokkaidô to near Mabutigawa (40°–41°N), and from Mabutigawa to South Hokkaidô (42°–43°N), the transfer of epicentres frequently occurs, but it is seldom that the transfer occurs in the reversed directions.

d) The regions near Mabutigawa and near Miyako (39°–40°N) are closely connected with each other as regards the transfer of epicentres.

e) It is interesting to observe that the regions, North Hokkaidô and Central Hokkaidô (43°–44°N) are indifferent to each other as for the occurrence of earthquakes. The regions, near Mabutigawa and near Kinkwazan are also independent with each other.

3) All Parts in Japan.

From Table III, *a*, *b*, we can remark the followings:—

a) An earthquake is liable to be followed by another in the same district.

b) If we connect different district in chain, choosing the pairs with large r's$>1{\cdot}4$, we obtain the following cycle or half-cycle for the "conspicuous" and "rather conspicuous" earthquakes and for the "destructive" earthquakes, respectively: Taiwan→Hokkaidô→Sanriku →Iwaki→Kwantô→Mutu→Sikoku-Kyûsyû→Taiwan.

Tôhoku→Hokkaidô→Kwantô→Sikoku-Tyûgoku→Nôbi-Hokuroku→ Taiwan→Sikoku-Tyûgoku.

Of course, this does not mean that the actual sequence of earthquakes occurs in this order, but that each successive pair of districts in this chain shows frequent connection in the temporal sequence of earthquakes.

c) Near Kinugawa and Iwaki are indifferent towards Mutu as for the occurrence of the "conspicuous" and "rather conspicuous" earthquakes, and also Taiwan and Nôbi-Hokuroku towards Tyôsen for the "destructive" earthquakes.

d) There is irreversibility of the directions of transfer of epicentres between Kwantô and Mutu for the "conspicuous" and "rather conspicuous" earthquakes, as well as Kwantô and Sikoku-Tyûgoku for the "destructive" earthquakes.

4) All Parts of the World.

From Table IV, and Fig. 8, *a*, *b*, we may be able to remark the followings:—

a) Among 8 regions, the Coast of the Mediterranean Sea and Continent of Asia, of which the boundary was assumed to be the line of longitude 50°, or Caspian Sea, as well as North America and Central America have large probability of occurrence of two earthquakes in succession in the same region while Japan has the least value of this probability ($r=0{\cdot}66$).
The rest of these regions have normal values of this probability.

b) From Continent of Asia, epicentres are liable to be transfered towards South America, but not to Central America. A similar relation holds for the cases, from Japan to the Philippines ($r=1{\cdot}65$), and to Australia ($r=0{\cdot}53$).

c) Epicentres are liable to be transfered in the direction such as to cross over the Pacific Ocean from Asiatic side to American side and also to travel about the Pacific Coast in counter-clockwise sense. Above all, Japan and South America seem to be intimately connected with each other as for the sequence of occurrence of earthquakes both before and after one another ($r=1{\cdot}64$ and $r=1{\cdot}80$), which may be considered to verify the result of the preceding paper[7] that an earthquake seems to be liable to induce another in the antipodal region.

d) It is of rare occurrence that the transfer of epicentre cross over the Atlantic Ocean.

e) For the transfer, Asia→South America, we have $r=1{\cdot}25$.

Investigations were also made as regards the probabilities that earthquakes occur in three regions in a definite sequence one after another. We can say yet nothing definite in this respect, as the data are still too scanty for this purpose.

5) Frequencies of the Time Intervals.

The frequency curve of the time intervals of the Great Earthquakes in the world seem to show a period of 27·5 days. The same period

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7) S. YAMAGUTI, *loc. cit.*, 5).

is obtained whether we choose 5 days or 10 days for the division of the time axis of the curve. This period seems to correspond to the period of rotation of the sun, 27·3 days, relative to the earth. In Fig. 9, *a*, the theoretical frequency curves, for random distribution, $f=ae^{-bt}$, are calculated, and in Fig. 9, *b*, the deviation curves are drawn.

The intervals of successive two earthquakes were classified into different groups according to the combinations of the two epicentral regions. The value of r for each pair of regions was assigned. Next, those pairs were picked up for which $r>1{\cdot}25$, and the frequency curve as well as the deviation curve were constructed for these earthquakes only as shown in the curve f_2 in Fig. 9, *a*, and *b*. The number of the cases taken is given there by N. Similarly f_3, f_4, were obtained for $r>1{\cdot}6$, and $r<0{\cdot}6$ respectively.

It is interesting to observe that the curves for large values of $r>1{\cdot}25$ ($N=118$), are parallel to those for the total earthquakes (f_1, $N=421$) while on the contrary, the curves for small r ($r<0{\cdot}6$, $N=33$), show a different course compared with the former.

The "destructive" earthquakes in Japan, taken from Rikwa-Nenpyô for which $r>1{\cdot}4$, ($N=25$ among the total of 151), during the period of 330 years (1600–1930), show the period of 363 and 727 days, which correspond to one year. The curves for the total number of earthquakes show the opposite course in the interval from 150 to 650 days and the parallel course in the interval over 650 days, compared with the above case (Fig. 10).

"Conspicuous" earthquakes taken from Kisyô-Yôran, during the period of 8 years (May, 1924–April, 1932) show the periods of about 45, 65 and 95 days, which are also observed as the secondary periods in the case of "destructive" earthquakes taken from Rikwa-Nenpyô above cited, while the particular groups for $r>1{\cdot}4$ ($N=20$) of the former earthquakes, show a somewhat opposite course (Fig. 11).

"Rather conspicuous" earthquakes in Japan, taken from Kisyô-Yôran, which occurred during the same period as above, show the periods of about 20, 38 and 53 days, (Fig 12, *a*), which are obtained either we divide the time axis by 5 days or overlapping 10 days interval. The maximum at about 13 days which is seen in Fig. 12, *a*, vanishes when the overlapping intervals of the time axis are taken as shown in Fig. 12, *b*.

For the "conspicuous" and "rather conspicuous" earthquakes in Kwantô Districts (May, 1924–April, 1932), the periods of about 23 and 38 days are seen from the deviation curves for the successive intervals of 5 days, as well as for the overlapping intervals of 10 days as shown in Fig. 13.

For the "felt" earthquakes in Kwantô Districts (May, 1924—April, 1932), the remarkable maximum of frequencies of occurrence takes place at 1 day (i. e. 12 hours–36 hours), and moreover, three maxima at about 3, 6 and 9 days (Fig. 14). The period of 9 days is also seen from the curve for the Great Earthquakes in the World, when we take 5 days for the division of the time axis.

In conclusion, I wish to express my best thanks to Prof. T. Terada under whose supervision the entire work has been carried out and who has given me many useful suggestions throughout the course of my investigation.

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5. 地震の時間的及び空間的分布に就いて

山　口　生　知

或る場所に一つの地震が起ると，或る特定の場所に引續いて地震が起り易いと云ふ事が，日本の地震學者に依つて既に述べられて居る.

本研究は此の說を統計的に確むべく，又所謂震源移動の方向と，氣壓匂配との間の關係を，調査する目的で行はれた.

それから又，この研究に依つて我國に於ける地殼の斷層線の存在及び位置を，見出す手懸ともならんことを望んだ.

又この研究は日本の各地に於ける地震に就いてのみならず，全世界の地震に就いても同樣に調査を進めた.

相次いで起る地震の間の，時間的間隔の統計的頻度に就いても，同樣の研究を進めて，地震の起り得べき週期を求めて見た.

其結果は關東方面に於いては，東北より南西の方向に所謂震源の移動の起り易いこと，及び震源移動の方向と，氣壓勾配との間には密接なる關係の有ることを發見した.

即ち磐城に於ける氣壓勾配の方向を基線として 0°, 45°, 及び 90° の方向に震源が最も移り易いことを知つた.

この 0° 及び 90° の方向は，切線應力及び垂直應力の方向に相當するので，豫め地殼の割目が存在するとすれば，此の割目の線に沿ふて地震の誘發を見るかも知れない.

又 45° の方向は剪斷應力の最大なる方向に相當するものと考へられる.

關東方面に於ける有感覺地震に就いて，一つの面白い事柄と思はれることは東京地方に地震が有

ると續いて霞ケ浦に地震の起る確率が非常に大きく，しかも霞ケ浦と接近して居る筑波に於いて地震の起ることに比較して，約三倍の値を持つて居ると云ふこと，及び之に反して駿河，甲斐地方に地震が有ると其の次には筑波に於いて起る可能性が大きく，霞ケ浦に於けるものゝ約五倍の値を持つて居ると云ふことである.

次に東北方面に於いて,震源が略々同一緯度內にて東西に移動することと,此の地方の區域に現はるゝ低氣壓の數との間には正の相關關係有ることを知り,其の相關係數として 0·47 と云ふ值を得た.

世界地震に就いては震源が亞細亞側より，亞米利加側に太平洋を，横斷する如き方向に移動する場合が多く，又太平洋岸を時計の針と反對の方向に移る場合が多い.

就中，日本と南米とは地震が互に相前後して起ることに關し密接な關係のあることを知り，「或る地點に起る地震は，地球上之と對蹠的位置にある地點の地震を誘導する」と云ふ前論文（本邦地震と世界各地地震の頻度間に存する統計的關係）の結果を一層明瞭に確めることが出來た.

尙世界地震に就いて，時間的分布を調べた結果 27·5 日と云ふ週期を得た. 之は恐らく地球に對する太陽の自轉の週期 27·3 日に相當するものと考へられる.

日本に於ける破壞的地震に就いては 363 日及び 727 日と云ふ約一年及び其の倍數に相當する週期を得た.

又關東地方全部の有感覺地震に就いては一日（12 時間—36 時間）と云ふ著しい週期の存在することを知つた.（第十四圖參照).