46. *Relation between Cyclone and Earthquake.*

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Introduction.

In a previous paper,[1] the mechanical stress produced in the earth's crust due to some mode of barometric pressure distribution on the earth's surface at the time of thunderstorm was considered as one of the agencies which may bring about a possible effect of thunderstorm upon the occurrence of earthquake. In connection with these problems, the relations between cyclones and earthquakes, firstly with regard to "deep" earthquakes and next with regard to "conspicuous and rather conspicuous" ones, are investigated statistically in the present paper.

It was aimed to find out the space distribution of epicentres with reference to the positions and the directions of propagations of cyclones frequenting the vicinity of the earthquake regions of Japan within 3000 kilometres, during the period of just 8 years, from 1926 to 1933.

It was also investigated, under what type of configuration of cyclones and anti-cyclones, the earthquakes are most liable to occur.

Lastly, the correlation between the pressure gradient and the depth of the "deep" earthquake, was sought.

The data for the earthquakes were taken from the Abridged Monthly Report of the Central Meteorological Observatory, and those for the cyclones, from the Daily Weather Charts of the North Pacific Ocean, published by the Imperial Marine Observatory, Kôbe in Japan.

Method of Investigation and Results.

1. *Frequencies of Distances.*

The distances to the epicentres of the "deep" earthquakes from the nearest cyclonic centres at the time of occurrences of the earthquakes, were respectively estimated, and the frequencies of cases with the dis-

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

tances falling in successive 200 kilometres, were counted. Such cyclones as are distant more than 3000 kilometres from the epicentres being disregarded. In comparing the relative frequency, the areas of zones between the concentric circles with radius of 200, 400, 600,....3000 kilometres, respectively, each with the epicentre as origin, must of course be taken into consideration. To eliminate this areal effect as well as the characteristic geographical distributions of cyclonic tracks regardless to earthquakes, the frequencies of the total cyclones, 3500 in number, falling on the same zonal areas between the concentric circles with "centre of gravity" of the "deep" earthquakes, near the coast of Siduoka, as origin, were counted. The value of the ratio, r_1, of the actual frequency, f_a, to the total frequency above cited, f_t, that is $r_1=f_a/f_t$, were calculated and plotted as ordinates, kilometres of the distance being taken as abscissa as shown in Fig. 1, (*a*), in which the smoothed curve in thick line was drawn by connecting the middle points of the successive two points.

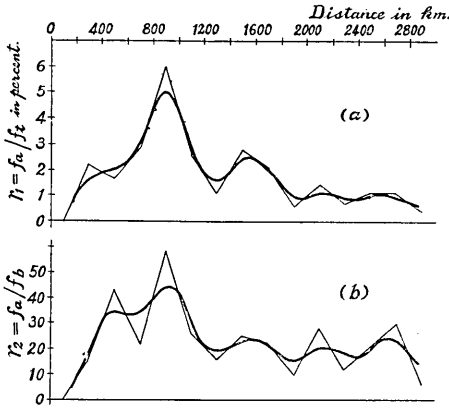

Fig. 1. Frequency of distances between cyclonic centres and epicentres of "deep" earthquakes.
f_a=actual frequency.
f_b=frequency regardless to earthquake.
f_t=frequency for the total cyclones.

From this curve, we can see at first glance that, very near the cyclonic centres, i. e. within 200 kilometres from them, "deep" earthquakes very rarely occur, and a remarkable maximum of frequency seems to exist about 900 kilometres apart from the cyclonic centres. This latter result seems to suggest that the region of maximum stress difference in the earth crust, due to cyclone, occurs at the places about 900 kilometres distant from the cyclonic centre.

To test, on the other hand, if the results may have any real physical meanings or not, with respect to the relation between the "deep" earthquakes and the cyclones, we have investigated an artificial case in which the positions of epicentres and cyclonic centres are given quite at random. About 270 epicentres of the "conspicuous and rather conspicuous" earthquakes and their corresponding cyclones were numbered 1, 2, 3, ...

270, respectively. A lot was drawn first, among a bundle of lots numbered from 1 to 270, to decide the number of epicentre corresponding to the first cyclone. Next a second lot was drawn to decide the number of epicentre corresponding to the second cyclone, and so on. With the artificial epicentres thus obtained, not corresponding to the cyclones actually, the similar frequency of distances, f_b, was obtained and the value of the ratio, $r_2=f_a/f_b$, was calculated and drawn, as shown in Fig. 1, (*b*). For the calculation of arbitrary frequency, f_b, it is necessary to take a pretty large number of earthquakes, so that we were obliged to take the "conspicuous and rather conspicuous" earthquakes instead of the "deep" earthquakes, of which the number was only 60.

The latter curve for r_2 has shown the character similar to that of the former r_1. Thus, these results seem to suggest some real physical meanings, with respect to the relation between the "deep" earthquakes and the cyclones.

Next, a quite similar treatment was applied for the "conspicuous and rather conspicuous" earthquakes. In this case, however, the epicentres are distributed in wide area along the Japanese Islands, compared with the former case with the limited area, so-called "deep" earthquake zones. Consequently, the value of the ratio, $r_3=f_a'/f_t'$, has shown a feature 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 cited in a previous paper,[2] the percentage value of $r_4=f_x/\sum f_x$, was calculated and drawn as shown in Fig.2, (*a*). The value of the deviation of r_3 from this value of r_4, i. e. $\Delta r=r_3-r_4$,

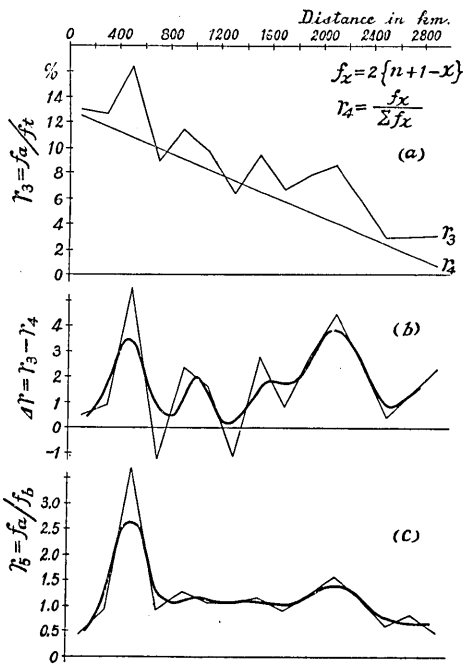

Fig. 2. Frequency of distances between cyclonic centres and epicentres of "conspicuous and rather conspicuous" earthquakes.

2) *loc. cit.*, 1).

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*).

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

2. *Azimuthal Distributions.*

Firstly, the azimuthal frequency of cyclonic centres referred to the epicentres, falling in the direction within each sector of azimuth angle 10°, was counted and named p_a. Also the similar frequency for the total cyclonic centres, p_t, referred to the centre of gravity of the epicentres of "deep" earthquakes above cited, was counted. The value of the ratio, $r_6=p_a/p_t$, as well as the value of the ratio of p_a to the frequency for arbitrary earthquakes, p_b, i. e. $r_7=p_a/p_b$, for the sake of comparison, were calculated and plotted in Fig. 3, in the case of the "deep" earthquakes. In the case of the "conspicuous and rather conspicuous" earthquakes, the corresponding values, $r_8=p_a'/p_t'$, and $r_9=p_a'/p_b'$, are plotted in Fig. 4.

The results are not so clear as in the case of distance distribution, but we may be able to see some maxima of frequencies in the directions E and W and also in two directions on both sides of south (160° and 200°) for the case of "deep" earthquakes, and similarly two maxima of frequencies in the west and S-E directions for the "conspicuous and rather conspicuous" earthquakes.

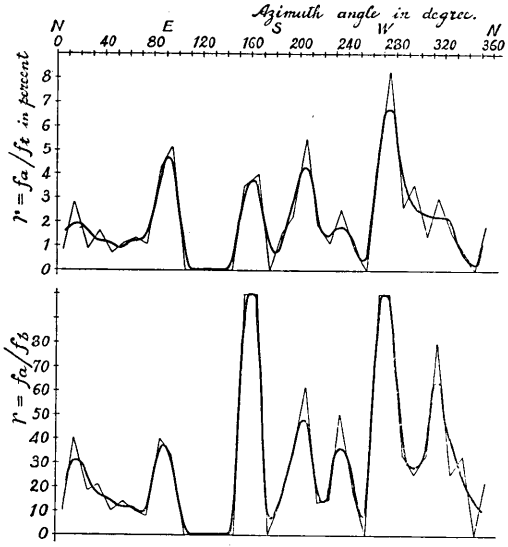

Fig. 3. Azimuthal frequency of cyclonic centres referred to the epicentres of "deep" earthquakes.

f_a=actual frequency.

f_b=arbitrary frequency for "the conspicuous and rather conspicuous" earthquake.

f_t=frequency for total cyclonic centres.

To make the physical meanings, if any, of the above results more clear, the number of cyclones, N, falling in a mesh made by dividing the wide area from Philippines to North Siberia (10°~60° N-latitude) and from West China to near Midway Islands (110°~180° E-longitude), with successive latitudes and longitudes of common difference of 5 degrees for each, were counted. The number, N, at the time of occurrence of the earthquakes during the period of 8 years, 1926~1933, was denoted by N_a, and its corresponding value for total cyclones at noon of the latitude

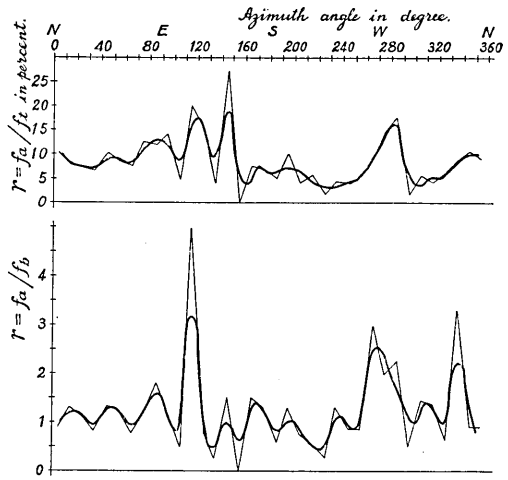

Fig. 4. Azimuthal frequency of cyclonic centres referred to the epicentres of "conspicuous and rather conspicuous" earthquakes.

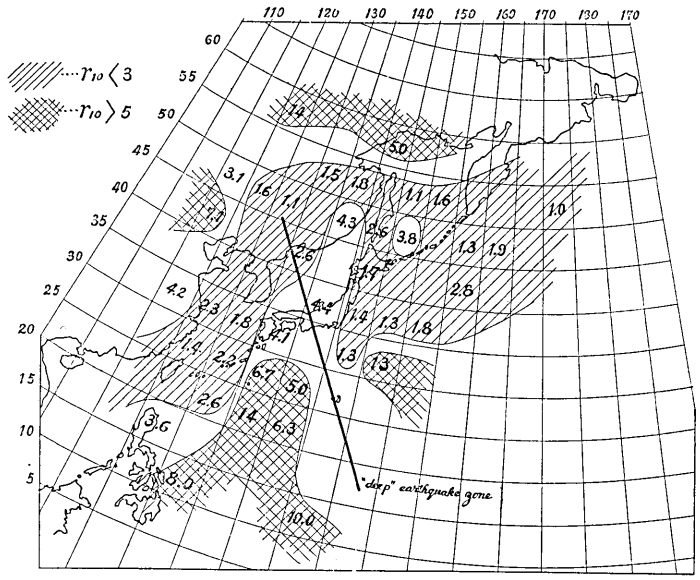

Fig. 5. The value of the ratio, $r_{10}=N_a/N_t$, in percent for the "deep" earthquakes.
N_a=number of cyclones at the time of occurrence of "deep" earthquakes.
N_t=total number of cyclones.

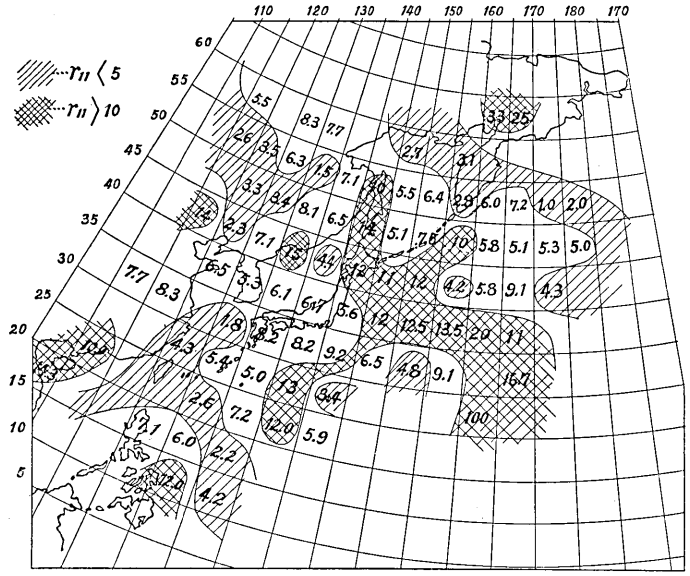

Fig. 6. The value of the ratio, $r_{11}=N_a'/N_t$, in percent for the "conspicuous and rather conspicuous" earthquakes.

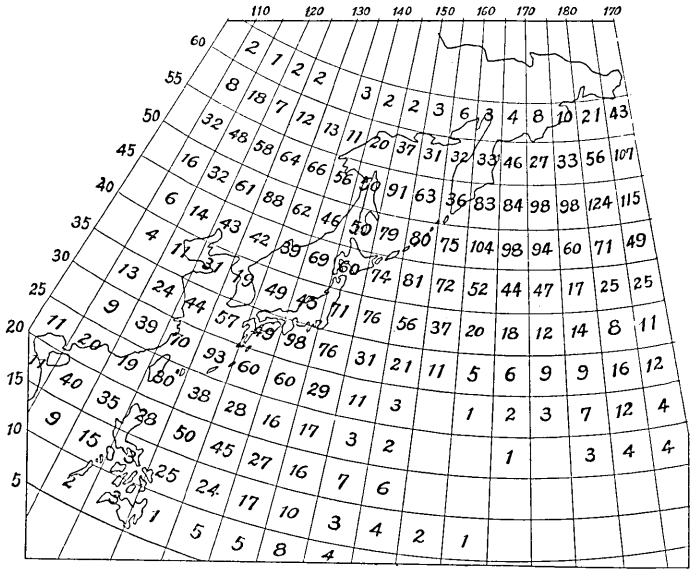

Fig. 7. Total number of cyclones at noon of the latitude of 135°E, during the period of 8 years, 1926~1933.

of 135°E on every day during the same period of 8 years, by N_t. The values of the ratios, $r_{10}=N_a/N_t$, and $r_{11}=N_a'/N_t$, were calculated and plotted on a map, respectively, as shown in Figs. 5 and 6, for the "deep" and the "conspicuous and rather conspicuous" earthquakes, the value of N_t itself being shown in Fig. 7.

The result seems to show that, on the "deep" earthquake zones, cyclones occur not much frequently than usual at the time of occurrence of the "deep" earthquakes, whereas just in the margin of the zones, the cyclones occur frequently at the time of earthquake.

For the "conspicuous and rather conspicuous" earthquakes, similar tendencies are seen and the cyclones frequenting the Pacific Ocean side seem to affect the occurrence of earthquakes more than those on the Japan Sea side.

These results are concordant, more or less, with the results already shown in Figs. 1~4.

For the sake of reference, the frequencies for the directions of propagations of cyclones, falling in the direction within each sector of azimuth angle 10°, (*a*) at the time of occurrence of the "deep" earthquakes, and (*b*) at the time of occurrence of the "conspicuous and rather conspicuous" earthquakes, were counted similarly as before, and plotted in *xy*-diagrams against the azimuth angle, *N*-direction being taken as zero, as shown in Fig. 8.

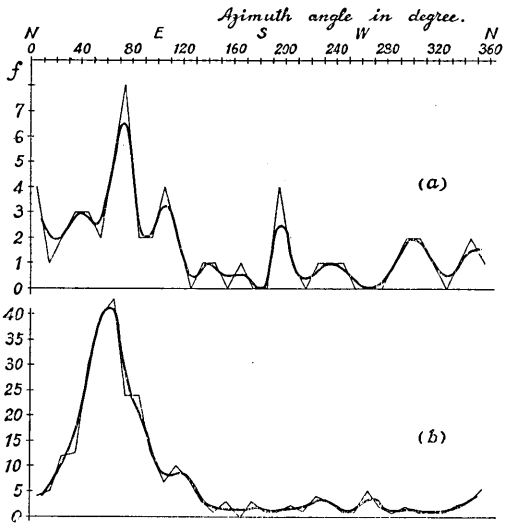

Fig. 8. Frequency of directions of propagations of cyclones.
(*a*) At the time of occurrence of "deep" earthquakes.
(*b*) At the time of occurrence of "conspicuous and rather conspicuous" earthquakes.

At the time of occurrence of the "conspicuous and rather conspicuous" earthquakes, as well as of "deep" earthquakes, only one conspicuous maximum of frequency for directions of propagations of cyclones exists at about N 60° E. This seems to be due mainly

to the fact that the latter direction is generally prevalent without regard to earthquakes.

Next, we investigated, in what directions, the earthquakes occur most frequently, referred to the centres and the directions of propagations of cyclones. The number of the earthquakes, φ_a, falling in the direction within each sector of azimuth angle 10°, which is formed by dividing all directions into 36 parts, were counted, angle being taken clockwise. The number of the arbitrary earthquakes, φ_b, corresponding to φ_a, were also counted, similarly as before. The values of the ratios, $r_{12}=\varphi_a/\varphi_b$, and $r_{13}=\varphi_a'/\varphi_b$, were calculated and plotted in vector diagrams, against the azimuth angle, the direction of propagation of cyclone being taken as zero, as shown in Figs. 9 and 10, respectively for the "deep" and "conspicuous and rather conspicuous" earthquakes.

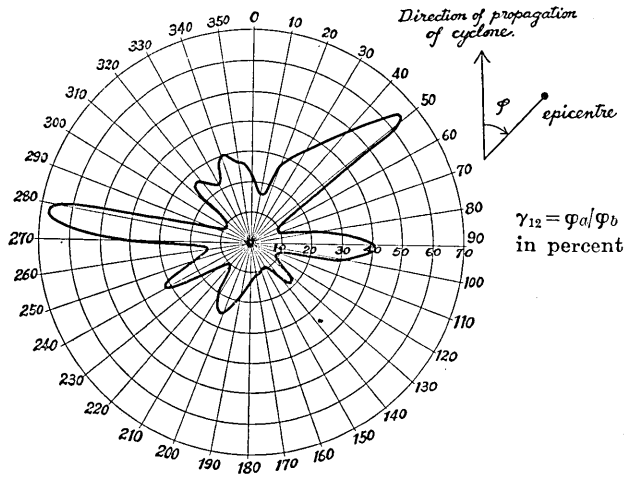

Fig. 9. Azimuthal frequency of the epicentres of "deep" earthquakes, referred to the direction of propagations of cyclones.
φ_a=actual frequency.
φ_b=arbitrary frequency for the "conspicuous and rather conspicuous" earthquakes.

The results show that, the "deep" earthquakes are liable to occur in transverse directions and also in directions inclined about 45° referred to the direction of propagation of cyclone, and that the "conspicuous and rather conspicuous" earthquakes seem to have a maximum frequency of occurrences about in the direction of propagation of cyclone, though slightly deviated towards right from it. There is another maximum, in the direction just to the left, and moreover small doubtful

maxima of frequencies are seen between these maximum directions inclined about 45° to them.

The physical meanings of these results are not yet clear, neither the data are sufficient for ensuring the result, so that this point may be reserved for the future investigations.

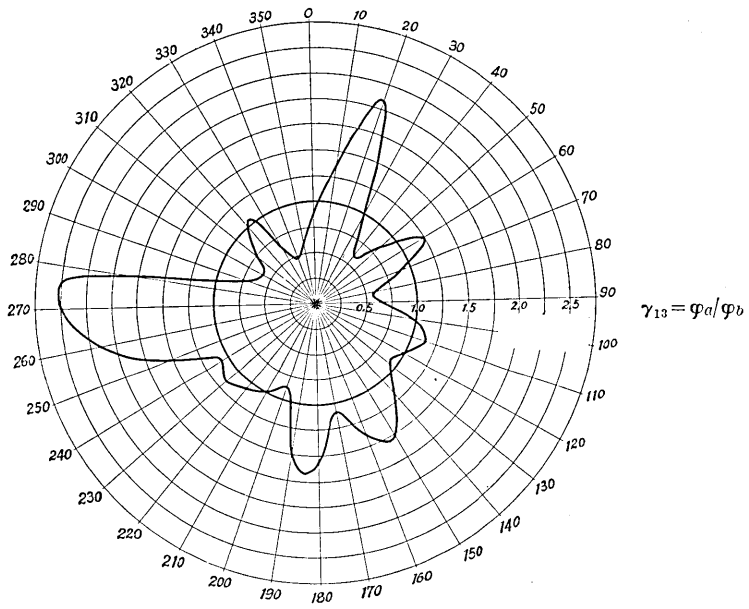

Fig. 10. Azimuthal frequency of the epicentre of "conspicuous and rather conspicuous" earthquakes, referred to the directions of propagations of cyclones.

3. *Arrangements of the Cyclones and the Anti-cyclones.*

To see, under what type of configuration of the cyclones and anticyclones surrounding the epicentre, the earthquakes are most liable to occur, the following procedure was made. All possible distributions of the low and the high pressure regions, were classified into five types as shown in Fig. 11, and the actual number of occurrences of earthquakes, M_a, belonging to each type, was counted from the weather charts on the days of actual occurrences of the earthquakes. The number of arbitrary earthquakes, M_b, corresponding to M_a, was similarly counted from the weather charts on the days without the earthquakes, the positions of the artificial epicentres being replaced for the actual ones by drawing a lot successively as already explained. The values of the

ratios, $r_{14}=M_a/M_b$, and $r_{15}=M_a'/M_b'$, were calculated respectively, for the "deep" and the "conspicuous and rather conspicuous" earthquakes, as shown in the annexed table.

	I-type	II-type	III-type	IV-type	V-type
"deep" earthquakes	$r_{14}=1{\cdot}5$	3·3	1·2	0·47	0·74
"conspicuous and rather conspicuous" earthquakes	$r_{15}=1{\cdot}3$	1·6	1·3	0·96	0·53

where

$$\sum M_a=\sum M_b=60,$$

and

$$\sum M_a'=\sum M_b'=283.$$

From this table, we may be able to say that the "deep" as well as the "conspicuous and rather conspicuous" earthquakes will occur most frequently in such arrangements of the low and the high pressures as represented by II-type, and rarely occur in the simple slope of pressure gradient as in V-type. And next, they are also liable to occur in the distributions of I-type and III-type. In IV-type, the "deep" earthquakes are rare, while the "conspicuous and rather conspicuous" earthquakes, occur indifferently.

These results must be re-examined where a more abundant material is available.

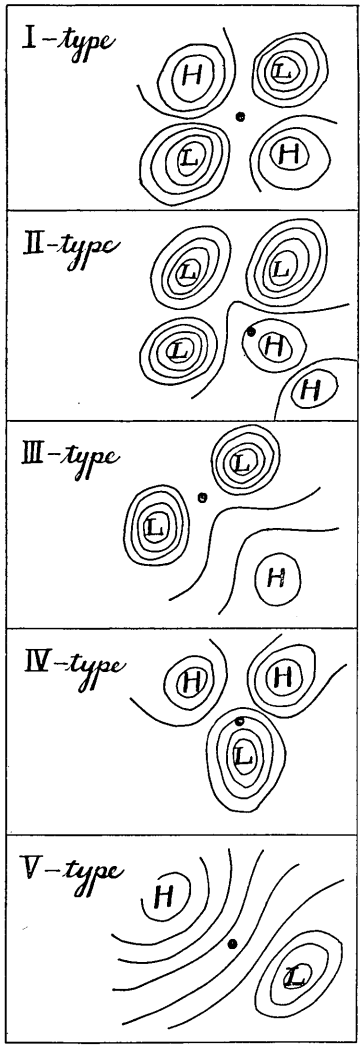

Fig. 11. Types of distributions of cyclones and anticyclones. ● marks the epicentre.

4. *Pressure gradient and Depth of "deep" earthquakes.*

Lastly, we have investigated the relation between the pressure gradient and the depth of epicentre.[3] Measuring the depression of the cyclonic centre, Δb, below the pressure at the position of the corres-

3) H. Honda and M. Takehana, *Kensin Zihô*, 8 (1934), 47.

ponding, or the nearest epicentre, and dividing it by the distance, d' between them, the provisory value of the gradient, $G=\frac{\Delta b}{d}$, was calculated in the unit of mm.Hg/100 km. Taking, G, as ordinate and the depth of the epicentre, as abscissa respectively, xy-diagram was plotted as shown in Fig. 12. The mean value of G's, falling in each interval of 20 kilometres of depths was obtained and marked by Δ, neglecting such point as exist only one in its belonging interval, and thus, the straight line was drawn by inspection so as to represent the general tendency of the relation.

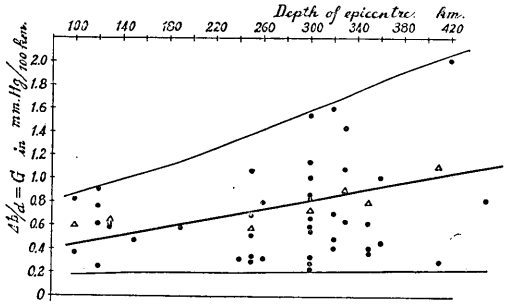

Fig. 12. Pressure gradient and depth of epicentre.
Δb=Depression of cyclone from the pressure at the position of epicentre.
d=Distance between epicentre and the nearest cyclonic centre.

Though the result is not quite decisive, we may be able to suggest a possible positive correlation between the pressure gradient and the depth of the epicentre.

To test, if the above relation may exist really or not, the mode of the variation of the frequencies of the "deep" earthquakes with various magnitudes of pressure gradients, between 0 and 2 mmHg/100 km., was investigated. The frequency, q_a, falling in successive 0·1 mmHg/100 km., was counted and plotted as ordinate against the pressure gradient, G, as shown in Fig. 13, (a). Similarly, the arbitrary frequency as above cited, q_b, corresponding to the pressure gradients on the days without

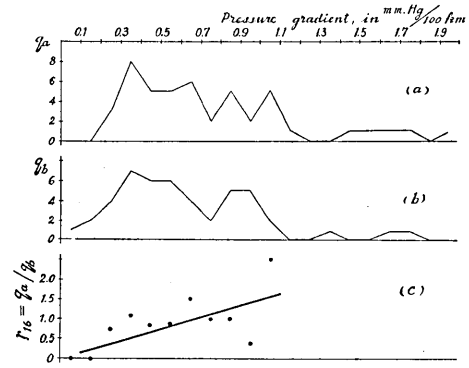

Fig. 13. Frequency of "deep" earthquakes in various pressure gradientes.
q_a=actual frequency on the days with "deep" earthquakes.
q_b=arbitrary frequency on the days without any "deep" nor "conspicuous and rather conspicuous" earthquakes.

any "deep" nor "conspicuous and rather conspicuous" earthquakes, was counted and plotted as before as shown in Fig. 13, (*b*). The value of the ratio, $r_{16}=q_a/q_b$, was calculated between the interval, 0～1·1 mmHg/100 km., and plotted as shown in Fig. 13, (*c*), in which a straight line inclined to the axis of G, may be drawn, representing the general tendency of distribution of eleven points.

The result that the value of the ratio, r_{16}, will increase with the increase of the value of pressure gradient, may be considered to verify the preceding result for some extent, and moreover shows that the real "deep" earthquakes could not occur with a small magnitude of pressure gradient less than 0·2 mmHg/100 km.

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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46. 地震と低氣壓との關係

地震研究所 山口生知

前論文(地震と雷雨との關係)に於て地震發生に及ぼす雷雨の動作の一として雷雨時の氣壓配置によつて地殻に或る機械的應力を與ふるであらうといふことを述べた．此問題と聯關して今度は地震と低氣壓との關係を調査してみた．低氣壓は大正 15 年より昭和 8 年まで滿 8 個年間に日本の地震帶附近震源より 3000 粁以内に現はれたものを採つた．その結果次のような事が言はれるかと思ふ．

1. 低氣壓の中心より 200 粁以内の所に於ては地震の起ることは極めて稀である．而して深發地震に於ては約 900 粁，顯著及び稍顯著地震に於ては約 500 粁の所に於て地震の起ることが最も多い．
2. 日本海方面に現はれた低氣壓よりも太平洋上に現はれた低氣壓の方が地震發生に及ぼす影響が大である．
3. 低氣壓の進行方向に關しては深發地震の場合は横の方向並びに進行方向より 45° 傾いた方向に於て起り易い．又顯著及び稍顯著地震の場合には進行方向から僅かに右へ傾いた方向及び丁度左の方向に地震頻度の最大があり，又是等の方向と約 45° 傾いた方向に疑はしくはあるが頻度の最大が在る．
4. 氣壓の配置が第 11 圖の II の型によつて示されるような時に地震が最も起り易く，V 型のような簡單な氣壓勾配の時には地震の起ることは稀である．
5. 氣壓傾斜の大さと深發地震の震源の深さとの間には極めて判然とではないが，先づ正の相關關係を認めることが出來るかと思ふ．(第 12 圖及 13 圖參照)．
