

27. *Distribution of Earthquakes in Japan.*

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Introduction.

The present investigation may be regarded as a continuation of the report given in a previous paper,¹⁾ dealing with the distribution of the "conspicuous and rather conspicuous" earthquakes, especially with reference to those experienced before and after the "deep" earthquakes in Japan.

The investigation was made with the intention of studying the geographical relation between the epicentres of the "conspicuous and rather conspicuous" earthquakes and the "deep" earthquakes, if such may exist, and to get a hint on the mechanism of occurrence of the "deep" earthquakes.

It was also aimed to find out the relation between these earthquakes and the cyclones which passed over the so-called "deep earthquake region."

We were obliged to take only the short period of investigation after 1926, as the data for the "deep" earthquakes are scanty before that epoch.

Those data for the earthquakes as well as the cyclones were taken from the Abridged Monthly Report of the Central Meteorological Observatory in Japan.

Method of Investigation and Results.

1. *Frequencies of Distances.*

The distances from the epicentres of "deep" earthquakes to the epicentres of the "conspicuous and rather conspicuous" earthquakes, which occurred immediately before and after the "deep" earthquakes, during the period of 6 years and half, Jan., 1926—June, 1932, were measured, and the frequencies of cases falling in successive 100 kilometres, were counted and plotted as ordinates, kilometres of the distances being taken as abscissa, as shown in Fig. 1, *a*. The similar frequency

1) S. YAMAGUTI, *Bull. Earthq. Res. Inst.*, 11 (1933), 46-68.

curve for the distances connecting the epicentres of two successive earthquakes taken, in the order of time of occurrences, for all the "conspicuous and rather conspicuous" earthquakes, which occurred during the same period, was drawn, as shown in Fig. 1, *b*, for the comparison with the above curve.

From these two curves, we can see at first glance that, before and after the "deep" earthquakes, the "conspicuous and rather conspicuous" earthquakes very rarely occur near the epicentres of the former, and their maxima of frequency exist at about 600, 950 and 1550 kilometres distant from the epicentres of the "deep" earthquakes, while on the contrary, the "conspicuous and rather conspicuous" earthquakes themselves, frequently occur at short distances one after another.

Next, to inquire after the meaning of this result more closely, the distances from the centre of gravity, G, (Lat. = 33° N, Long. = $138^{\circ}.4$ E), of the epicentres of all the "deep" earthquakes which occurred in the region between the sea off Idu and Kumanonada, to the epicentres of the "conspicuous and rather conspicuous" earthquakes in all Japan, excluding

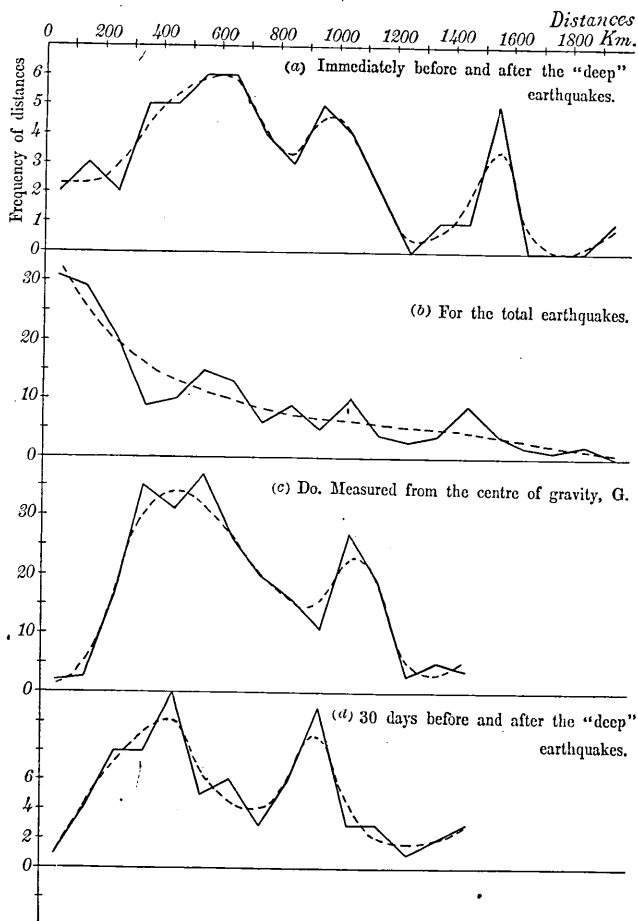


Fig. 1. Frequency and distance curve for the "conspicuous and rather conspicuous" earthquakes.

A similar characteristic curve may be drawn with reference to the earthquakes which occurred within 30 days before and after the "deep" earthquakes, as shown in Fig. 1, *d*.

Next, we have drawn a circle with a radius of 1050 *km.*, and with a point in the coast of N. Corea (Lat. = 42°N, Long. = 130°E) as centre, of which the circumference touches the coast of Sanriku and the promontory Murotozaki in Tosa. The circular arc was divided into equal sectors by radii vector subtending an angle of 10°, $x = -5, -4, \dots -1, 1, 2, \dots 8$, where the prime vector $x=0$ passes through the centre of gravity, *G*, as shown in Fig. 2, in which, the epicentres of the "conspicuous or rather conspicuous" earthquakes and the "deep" earthquakes are marked by \circ and \bullet , respectively, the numbers affixed to the epicentres of the latter class, showing the order of time of occurrence. Referring to this map, the number of "conspicuous and rather conspicuous" earthquakes, and also that of "deep"

earthquakes falling in each sector were respectively counted, and plotted against the sector number, x , as shown in Fig. 3, *a, b*, respectively.

From these curves, we remark that, near the point of maximum frequency of the "deep" earthquakes, very few "conspicuous and rather conspicuous" earthquakes occur, and that three conspicuous maxima of frequencies

of the latter are found in the regions at $-30^\circ, 30^\circ$, and 60° measured from the maximum of the former. These results essentially agree with the preceding results as may be expected.

With regard to these results, Prof. T. Terada suggested, that if a spherical part of the crust at the "deep" earthquake epicentre lying several hundred kilometres beneath the earth surface, happens to expand or yield by some cause, the maximum stress may occur in a conical surface with semivertical angle of about 45° and the vertex at the centre of sphere, and the fracture may propagate along these directions towards the earth surface. Therefore, the "conspicuous and rather conspicuous" earthquakes of shallow origin rarely occur near the epicentral region of

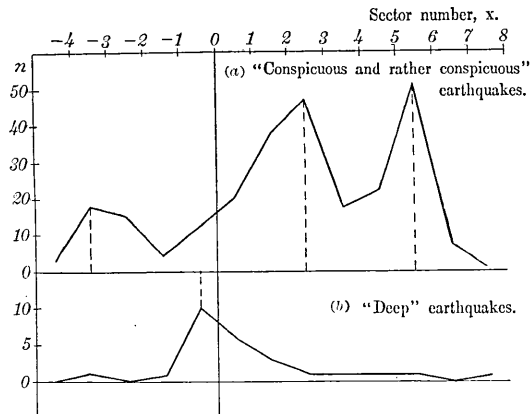


Fig. 3. Number of earthquakes in various regions.

the "deep" earthquakes, but frequently occur in the regions about 500 *km.* apart, which distance is comparable to the depth of the "deep" earthquakes.

To investigate the character of radial (i. e. in the direction normal to the arc of Japan) distribution of the "deep" earthquakes, the radial distances, y , (+ y , directed outward, or towards Pacific Ocean side) were measured from the circumference of the circle above described (Fig. 2), and plotted against the time axis, as shown in Fig. 4, in which the times of occurrences of the "destructive" earthquakes and the great volcanic eruptions were marked on the curve, and on the time axis, by | and \circ respectively. The result seems to show some alternate radial "transfer" of epicentres of the "deep" earthquakes with the period of 3.5 years, as far as can be judged from the present scanty materials.

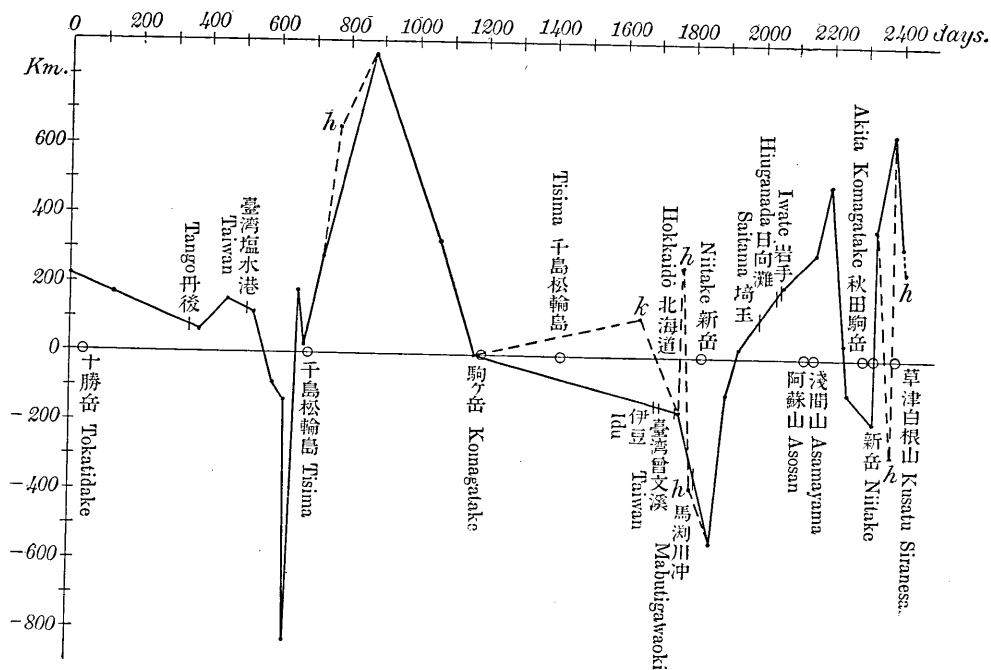


Fig. 4. Time and radial (normal to the arc of Japan) distance diagram for "deep" earthquakes. Dotted line is obtained, if we include the earthquakes in Hokkaidô and Kyûsyû.

- h : near Hokkaidô, k : near Kyûsyû.
 | "destructive" earthquakes.
 \circ great volcanic eruption.

2. Relation between Earthquakes and Cyclones.

The number, n , (a) of the "deep" earthquakes above cited, for successive 3 months, was counted and plotted against the time axis, those which occurred near Hokkaidô being omitted, as shown in Fig. 5, a. Similarly, (b) for the "conspicuous and rather conspicuous" earthquakes, which occurred in the region from Kyûsyû to the sea off Sanriku ($x = -4 \dots +4$), and (c) also for those which occurred in the maximum-frequency-regions only, i. e., near Kyûsyû and near the sea off Iwaki, as well as (e) for the "felt" earthquakes, which occurred in the region from Wakayama to Idu ($x = -1 \dots +1$), the curves for n were drawn

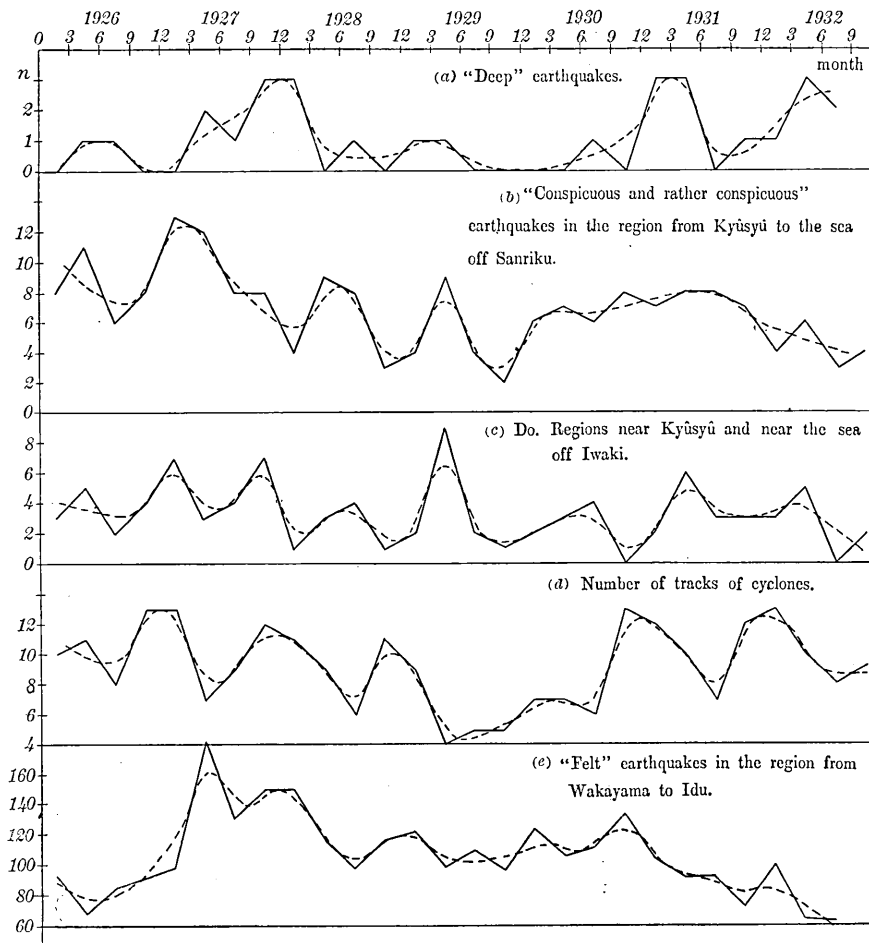


Fig. 5. Number of earthquakes and the tracks of cyclones for three months.

as shown in Fig. 5, *b*, *c*, and *e*, respectively. On the other hand, (*d*) the number of tracks of cyclones, which passed across the line $x=0$, between the limited length of $y=\pm 1000$ km., for successive 3 months, were counted, and similarly plotted as shown in Fig. 5, *d*.

Looking at these curves, there seems to exist some fluctuations of a long period superposed upon an annual period.

Comparing the curves for the "deep" as well as the "conspicuous and rather conspicuous" earthquakes, with that for the cyclone, we may recognize some parallelism between the fluctuations of the longer period, and a nearly opposite course between those of annual period in general. Thus, we assumed that the curve for the earthquakes, E , to consist of two parts, i. e., one of the longer period, E_l , and the other of annual period, E_a , and $E=E_l+E_a$. Similarly, for the cyclons, we denoted by $C=C_l+C_a$. Assuming $C_l=kE_l$, and $C_a=-kE_a$, where $k=\frac{\sum|\Delta C|}{\sum|\Delta E|}$, we have $C_l=\frac{1}{2}(C+kE)$. Now, if the relation, $C_a=-kE_a$, holds exactly,

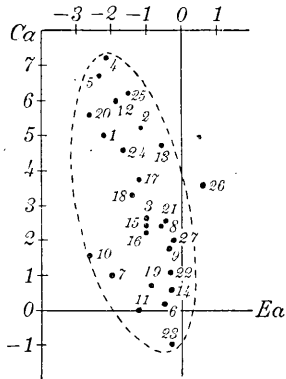
C_l -curve, thus obtained, must be a smooth periodic curve. Though it is by no means so smooth actually, we have smoothed this curve by connecting successive mean points. The readings of C_l were taken from this smoothed curve, and the values of $C_a=C-C_l$, were calculated. Similarly, the values of E_a were obtained, and C_a-E_a diagrams were drawn, taking 4 combinations of respective earthquakes and the cyclone, above cited, as shown in Fig. 6, *a*, *b*, *c*, *d*.

The results show that the "deep" earthquakes as well as the "conspicuous and rather conspicuous" earthquakes of the two kinds, have the negative correlations with respect to the cyclone for some extent, while on the contrary, the "felt" earthquakes has the positive correlation with the cyclone.

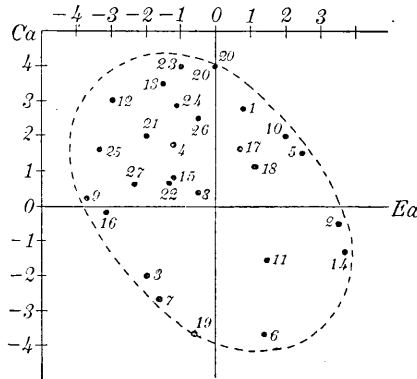
As to the physical meaning of these results, we may suggest the followings:—

a) The excessive stress, stored in the relatively shallow portion of the earth crust, may be released by frequent occurrence of the earthquakes of such a degree as the "felt" earthquakes, which are affected directly by the cyclone frequenting the region.

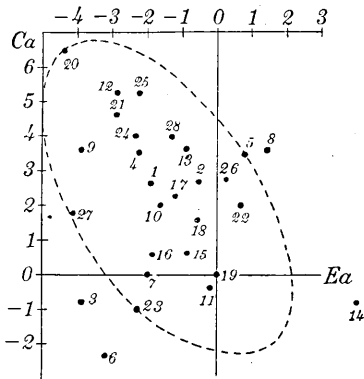
b) When the release of the excessive stress due to the "felt" earthquakes is comparatively little, then the earthquakes of such a degree as the "conspicuous and rather conspicuous" or the "deep" earthquakes will occur.



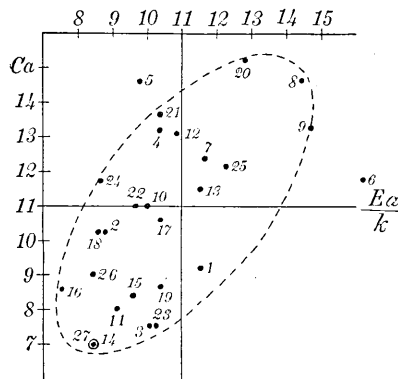
(a) "Deep" earthquakes.



(b) "Conspicuous and rather conspicuous" earthquakes in the region from Kyūsyū to the sea off Sanriku.



(c) "Conspicuous and rather conspicuous" earthquakes in maximum-frequency-regions only.



(d) "Felt" earthquakes.

Fig. 6. Earthquakes and cyclones curves.

In the case of those "conspicuous and rather conspicuous" earthquakes which occurred in the maximum-frequency-regions only, apart from the "deep" earthquake region by some 500 km., the relation is not so clear as in the other cases, the cyclonic effect being probably effaced by other causes such as the characteristic "habit" of those districts with regard to the occurrence of earthquakes; nevertheless, we have a small negative correlation coefficient of -0.23 , applying the ordinary formula for calculation.

3. Frequencies of the Time Intervals.

The time intervals from an occurrence of the "deep" earthquake to the next one, were examined, and the frequencies for the intervals of successive 10 days, were counted and plotted as ordinates, the days of the intervals being taken as abscissa, as shown in Fig. 7, *b*. For the sake of comparison, the similar curve for the "conspicuous" earthquakes in Japan, $N=124$, as well as the deviation curve for the Great Earthquakes in the world, $N=421$, were drawn once more as shown in Fig. 7, *a*, *c*, reproduced from a previous paper.²⁾

The "conspicuous" earthquake in Japan has very large frequencies for the short time intervals less than 20 days, especially, less than 10 days, while the "deep" earthquake has relatively small frequencies for the shorter time intervals compared with the case of purely accidental distribution.

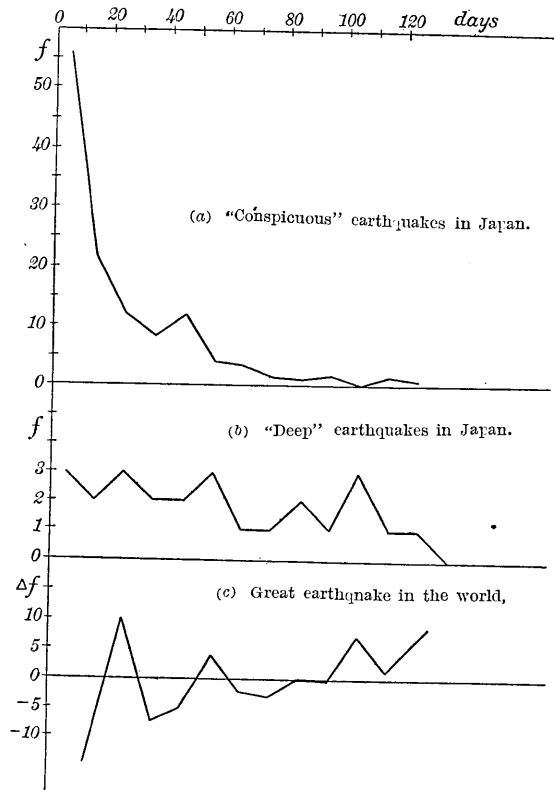


Fig. 7. Frequencies of the time intervals.

The "deep" earthquake seems to show the periods of about 27.5, 55, and 105 days, which nearly correspond to the period of rotation of the sun, 27.3 days, relative to the earth, in fair coincidence with those for the Great Earthquakes in the world.

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

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

has given me many useful suggestions throughout the course of my investigation.

27. 日本に於ける地震の分布

山 口 生 知

本研究は、前論文「地震の時間的及び空間的分布に就て」の續きとして特に日本に於ける深層地震前後の顯著及び稍顯著地震の分布に就いて、調査したものである。

即ち顯著及び稍顯著地震の震源と、深層地震の震源との間に存する地理的關係を研究し、延いては、深層地震の起り方の機巧に關して何か一つの手掛りを得んと試みた。

又之等の地震と所謂深層地震帶を通過した低氣壓との間の關係を見出さん事をも望んだ。之等の結果として吾々は次の事柄を知つた。

(1) 深層地震の前後に於いては、顯著及び稍顯著地震は深層地震の震源附近に於いて起ることは極めて稀にして、此處より約 500 軒、及び 1000 軒、等の地點に於いて最も起り易いことを知つた。(第一圖參照)

此結果に關し寺田寅彦博士は次の如き考へを暗示された。

即ち「地球の表面より數百軒の深さの處に深層地震の震源たるべき地殻の或る球狀の部分は何等かの原因に依つて、膨脹或は收縮するならば、この球の中心に頂點を持ち、半頂角 45° なる圓錐面上に於いて最大應力が起り、其の破壊は、これ等の方向に沿ふて地表に向つて傳はるものと考へられる。それ故に淺い震源を有する顯著及び稍顯著地震は、深層地震の震源附近に起ること稀にして深層地震の深さと同程度なる約 500 軒を隔つる地方に屢々起ることとなるものであらう」と

(2) 深層地震並びに顯著及び稍顯著地震は低氣壓と負の相關々係を有し、有感地震と低氣壓とは正の相關々係あることが認められる。(第六圖參照)

此の物理學的意義に關しては、吾々は次のように考へることが出来るかと思ふ。

即ち地殻の比較的淺い場所に蓄積された餘分の應力は、直接低氣壓の影響を受けて、屢々誘發されるところの有感地震程度の地震に依つて、濟し崩し的に解放される。

而してこの蓄積された餘分の應力の解放が比較的少ないような時に、顯著及び稍顯著地震、或は深層地震が起るものと考へられる。

(3) 時間的分布に就いて言はれることは、日本に於ける顯著地震は 20 日以内特に 10 日以内と云ふような短い時間的間隔内に於いて、非常に多く起り易いのに反し、深層地震は、純然たる偶發的分布の場合と比較すれば、短い間隔内に於いて起る度数が割合に少ないと言ふことである。

又深層地震は太陽の自轉の週期 27.3 日に相當する 27.5 日、55 日、及び 105 日と云ふ週期を持つてゐる。而して之等の週期が世界地震の週期とよく一致して居ると云ふことは、面白いことと思ふ。(第七圖參照)