15. *World Distribution of "Deep" Earthquakes.*

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(Read Oct. 20, 1936.—Received Dec. 21, 1936.)

Introduction.

The object of the present investigation was to ascertain the vertical distribution of foci of "deep" earthquakes, especially of the world's "deepest" earthquakes.

It was also hoped that some knowledge regarding the existence of "weak lines" in the earth's crust and their locations.

The statistical periodicity of "deep" earthquakes was also investigated and the probable "periods" of occurrence obtained.

V. Conrad[1], who has made similar investigations, in summarizing his paper entitled "Die Zeitliche Folge von Beben mit tiefem Herd", writes:

"From the frequency of deep-focus earthquakes given in the I. S. S. (International Seismological Summaries 1919~28) it is not possible to find any periodicity for a day's length, whether the epicentral-time given be local or world-time. No clustering of earthquakes near days of full or new moon could be found.

Although a real periodicity for a whole year calculated on the basis of monthly frequencies is not improbable, that for a length of six months is probable—a fact seemingly important since all the writer's previous studies of earthquakes with shallow focus have shown such periodicity.

A periodogram of the frequency of these earthquakes (grouped in this case in tenths of a year) does not, it is true, show a trial-period for which A. Schuster's criterion would indicate reality. But there are in the periodogram three sharp peaks at five-, ten-, and twelve-tenths of a year. The half-year periodicity found in the first part of this and previous studies on this subject seems to point to rotation of the earth's pole as the cause of the variations in frequency, the probability of which seems to be supported by the fact as pointed out by Pollak that

1) V. CONRAD, *Gerl. Beitr. Geophys.*, **40** (1933).

thc only harmonic components in the rotation of the earth's pole are the two periods of ten- and twelve-tenths of a year. It is therefore likely that in the future increased statistical material will enable one to see in the rotation of the pole one of the causes of both deep- and shallow-focus earthquakes.

Of the series obtained by dividing the scanty *eo ipso* material in two halves, the frequency of earthquakes of more shallow focus shows half-year periodicity in a fairly clear manner."

The data of the world's "deep" earthquakes during the period of twelve years from 1919 to 1930 were taken from the International Seismological Summary, collected by H. H. Turner. In Turner's list of earthquakes (I. S. S.), such terms as *normal depth, below normal, above normal,* are used for roughly classifying the depths of earthquakes, the *normal depth* and the earth's radius for calculating the focal depths having probably been taken as 255 and 6370 kilometres respectively.

Method of Investigation and Results.

1. Geographical and Vertical Distribution.

The epicentres, as many as 241, are plotted on a map of the world. The numerals against the points that represent the hypocentres show their focal depths, h, in kilometres. The points thus plotted for many regions of the world were separated into four parts with contour lines of 700 km, 500 km, and 300 km, such as $h \geqq 700$, $700 > h \geqq 500$, $500 > h \geqq 300$, and $300 > h \geqq 100$, for the respective regions as shown in Fig. 1.

A mere glance will show that the deepest regions are near Japan, in the middle part of South America, the southern part of the Philippines, and the ocean east of Australia. Of these, there are several "deep" earthquakes with greater depth of foci than 800 kilometres, although it is possible that the depths of earthquakes, as estimated by Turner exceed somewhat those made by a number of seismologists in Japan. Near Japan, two of the three deepest regions are situated at each end of the so-called "deep" earthquake zone, i. e., in the ocean beds near the Ogasawara (Bonin) Islands and on the main land of Manchuria, the third being in the Okhotsk Sea. Comparatively shallow earthquakes occur in the middle of the Asiatic continent, in Africa, and in the southern sea bed of the island of Sumatra.

We also notice a distinct difference between the geographical distribution of "deep" earthquakes and that of "shollow" earthquakes. Deep focus earthquakes do not occur on the Mediterranean Coast; they rarely occur in North America, especially on its Pacific Coast, while shallow

earthquakes frequently occur in the regions just mentioned as well as in other regions of the world.

By projecting the centres of the "deep" earthquakes in South America on a vertical plane containing the equator, which diagram is omitted here, we notice that a number of points tend to lie in a zone, through the deepest region, i. e. the middle part of South America, and inclined toward the Pacific Ocean with a slope of about 1/5 from the horizontal.

As for the "deep" earthquakes that occurred in the Continent of Asia, we notice a similar tendency, i. e. the focal depths become shallower as the longitude eastward increases, from the Plateau of the Pamirs to the eastern part of Tibet.

2. Hypocentral "transfer" in Vertical direction.

i) For the world's "deep" earthquakes.

Owing to the data being very scanty, we had to calculate the preferential ratios for the case of hypocentral "transfer" in radial direction of the earth, regardless of the geographical distribution of earthquakes. By preferential ratio, r, is meant the ratio of the actual number of times the "transfers" have occurred, N_0, to, N', the expected number obtained by calculation, that is $r=N_0/N'$, as already explained in a previous paper[2]. The values of the ratios r's were calculated for six layers separated according to their depths, such as $100 \leqq h < 300$, $300 \leqq h < 400$, ... $600 \leqq h < 700$, and $h \geqq 700$, in kilometres, as shown in Table I.

Table I. Radial hypocentral "transfer" of the world's "deep" earthquakes. Jan., 1919~Dec., 1930 (whole 12 years).

		Region of the second of the two earthquakes					
		100~300 km	300~400 km	400~500 km	500~600 km	600~700 km	700→ km
Region of the first of the two earthquakes	100~300	**5·33**	*0·38*	0·67	1·21	0·67	*0·58*
	300~400	0·57	1·25	0·89	0·80	1·02	*0·66*
	400~500	*0·33*	0·82	**1·63**	**1·33**	0·65	1·12
	500~600	*0·30*	1·03	1·03	1·23	0·91	1·04
	600~700	1·33	0·76	0·98	0·91	**2·00**	1·16
	700→	*0·58*	0·99	*0·56*	0·78	1·16	**2·49**

Judging from this table, we may say that

(*a*) When an earthquake occurs in a certain layer, other earthquakes are liable to occur immediately in the same layer.

2) S. YAMAGUTI, *Bull. Earthq. Res. Inst.*, **11** (1933), 50.

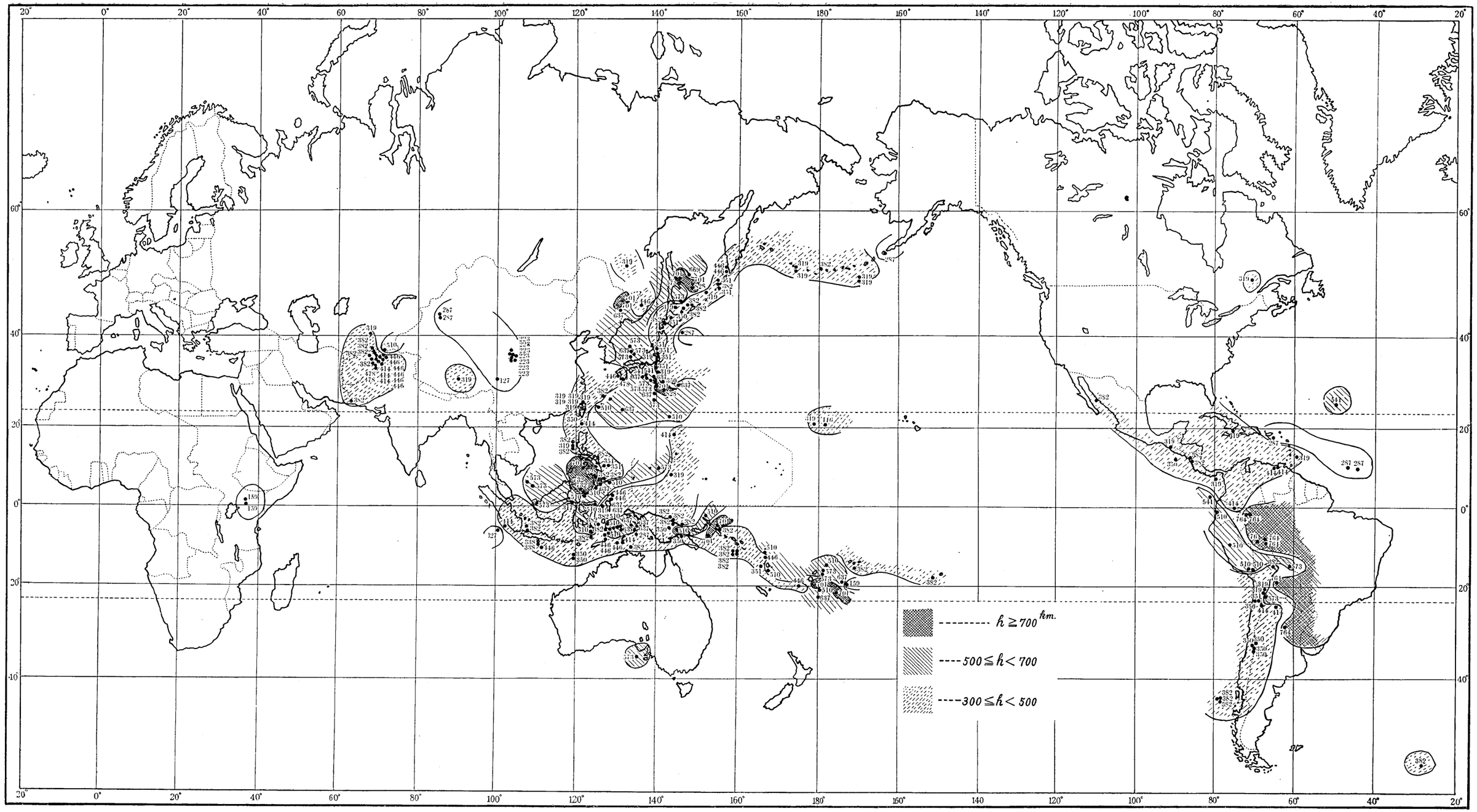

Fig. 1. Geographical and Vertical distribution of "Deep" earthquakes. The numerals against the points that represent the hypocentres show their focal depths, h, in kilometres.

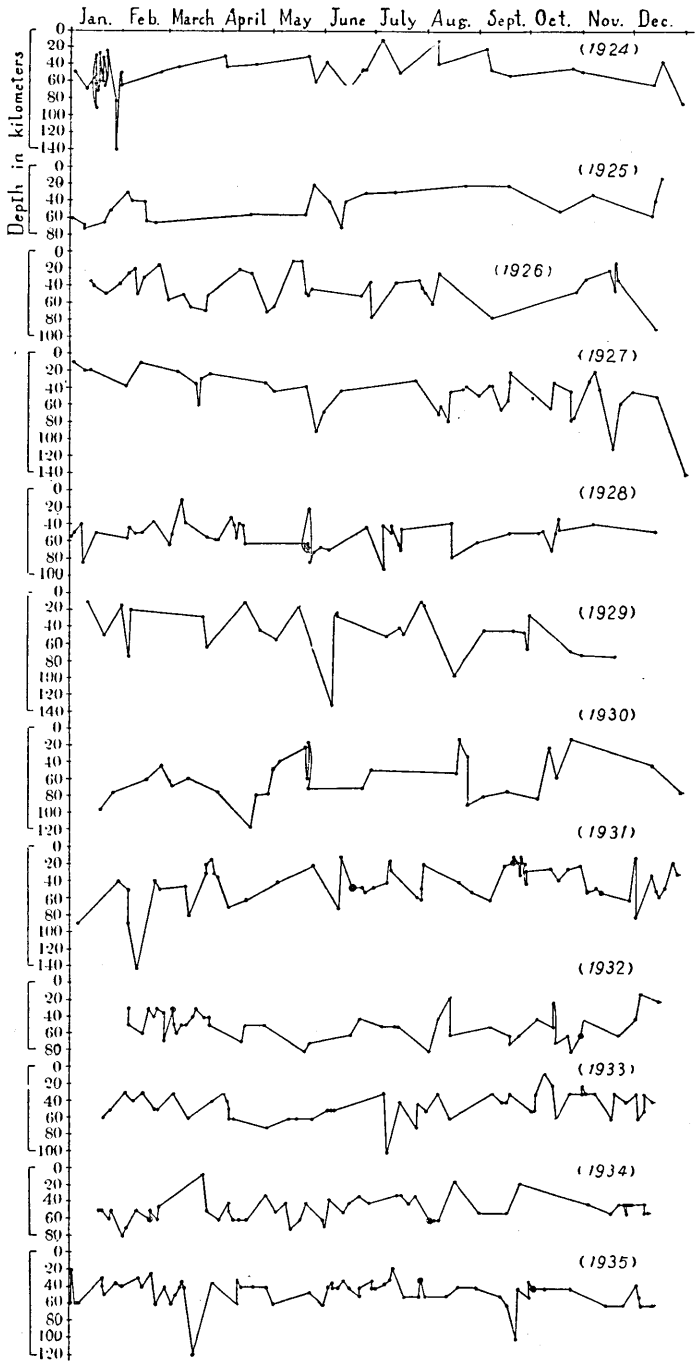

Fig. 2. Depth Time diagram for the "felt" earthquakes in Kwantô Districts.

(*b*) Earthquakes are most likely to occur in the layer 500～600 next to the layer 400～500.

(*c*) The chances of hypocentral transfers are small in such ranges of layers as 100～300→300～400, 300～400→over 700, 400～600→100～300 and over 700→400～500.

(*d*) The relations between the two layers, 100～300 and over 700, do not seem to be amenable to successive occurrence of earthqukes.

ii) For the "felt" earthquakes in Kwantô Districts.

There are only 553 earthquakes of which the hypocentral depths are known. They were felt in Tokyo during the period of 12 years from Jan. 1924 to Dec. 1935 and taken from Seismometrical Report of the Earthquake Research Institute, Tokyo Imperial University, and the depths were plotted as ordinate against the time axis, as shown in Fig. 2. From this diagram, the preferential ratios for the case of hypocentral "transfer" in vertical direction for five layers, 0～20, 20～40, 40～60, 60～80, and over 80, kilometres depth, were calculated similarly as before and given in Table II.

Table II. Vertical hypocentral "transfer" of the "felt" earthquakes in Kwantô Districts. Jan., 1924～Dec., 1935 (whole 12 years).

		Region of the second of the two earthquakes				
		0～20km	20～40km	40～60km	60～80km	80km→
Region of the first of the two earthquakes	0～20 km	1·38	**1·68**	0·83	0·34	1·46
	20～40	1·26	1·05	0·95	0·93	1·19
	40～60	1·15	0·99	1·13	0·78	0·85
	60～80	*0·56*	0·80	0·88	**1·53**	0·90
	80→	0·49	0·75	0·94	**1·35**	1.36

Although we can say nothing definite of the results, we might say that

(*a*) An earthquake in a certain layer is liable to be followed by another in the same layer, particularly in the layer 60～80.

(*b*) From layer 0～20 to layer 20～40, and also from layer over 80 to layer 60～80, transfer of hypocentres frequently occurs.

(*c*) The layers 0～20 and 60～80 are independent of each other with reference to sequences of earthquakes in both directions, to and from.

3. Periodicity of the world's "deep" earthquakes.

Not only the time intervals between the occurrence of a "deep" earthquake and the next one, the number of which is $N=240$, but also

the time intervals between the occurrence of a "deep" earthquake and the second, third, fourth, fifth, and sixth, the number of which is $N'=1168$, were taken, and the frequencies of these intervals for every 10 days counted and plotted as ordinates, the intervals being taken as

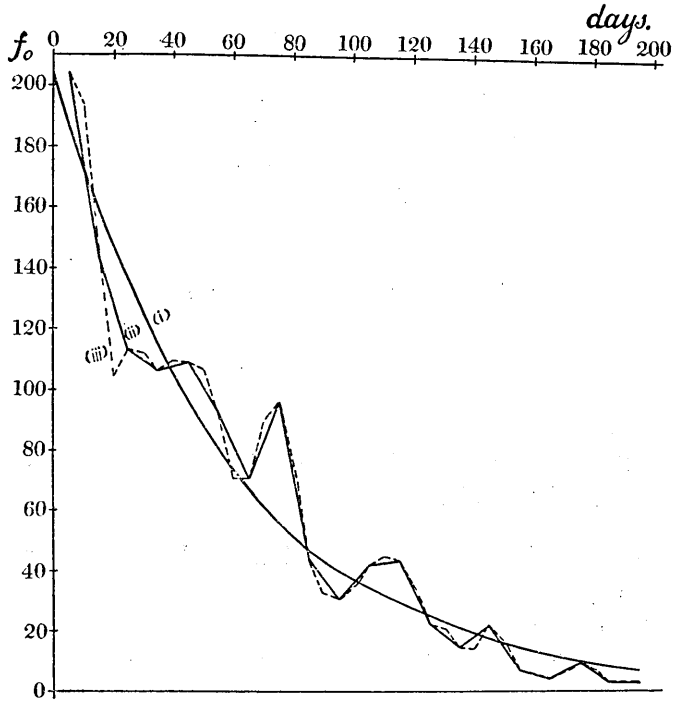

Fig. 3. Frequency of time intervals between the occurrence of a "deep" earthquake and the second, third, fourth, fifth, and sixth, the number of which is $N'=1168$.
(i) $f_t=204\,e^{-0.017t}$
(ii) Every 10 days' intervals.
(iii) Every 10 days' overlapping intervals.

abscissa, as shown in Fig. 3. for the case of N'. The intervals of time for N' were especially taken in this case in order not to miss such particular series of earthquakes as are intimately connected with one another in bringing about the sequences of earthquake occrrence, if such sequences do exist.

The general trend of the curve shows that earthquakes occur at random. We calculated the frequency f_t for purely random occurrences, assuming $f_t=a\,e^{-bt}$, and obtained the deviations in actual frequencies from the theoretical value of f. In order to satisfy ourselves that the periodicity of the deviation curve is not due to an apparent one common to any accidental phenomena, we also tried to take the overlapping

intervals of days for comparison. The deviation curves for N' are shown in Fig. 4, a, and b.

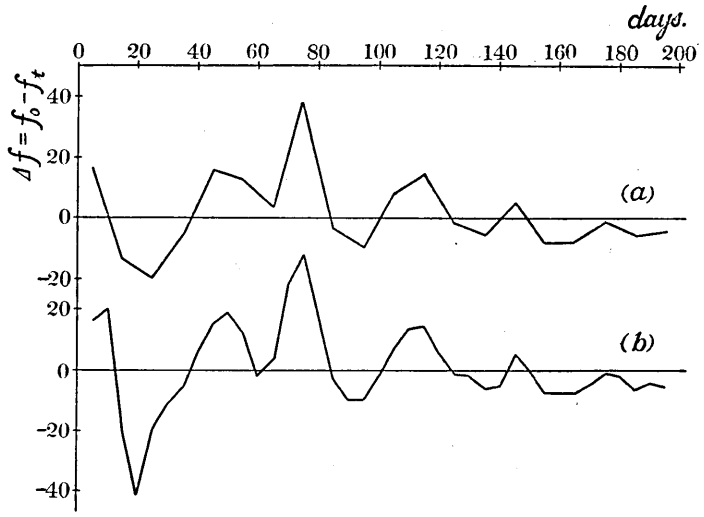

Fig. 4. Deviation of frequency in the case of $N'=1168$.
(a) Every 10 days' intervals.
(b) Every 10 days' overlapping intervals.

In the case of N also, it was treated similarly as N', and deviation curves were drawn as shown in Fig. 5, a, b.

Fig. 4 shows many maxima of frequencies of time intervals at about 45, 75, 115, 145, and 175 days. The period of 175 days corresponds nearly to V. Conrad's semi-annual period, which was regarded by him as being likely, and which may correspond to the rotation period of the earth's pole.

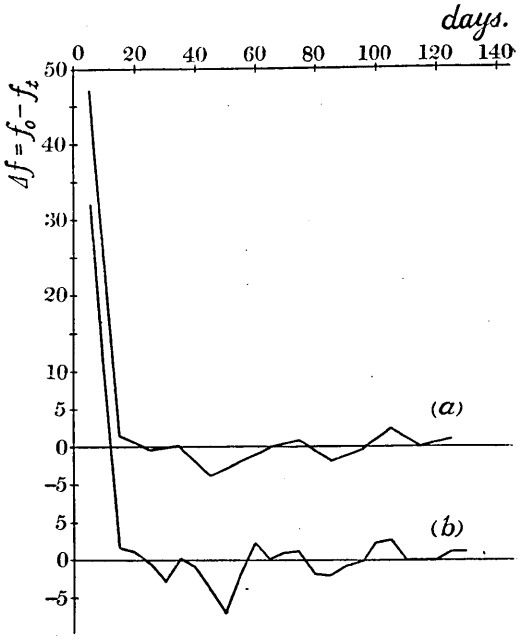

Fig. 5. Deviation of frequency in the case of the time intervals between successive two earthquakes ($N=240$).
(a) Every 10 days' intervals.
(b) Every 10 days' overlapping intervals.

Although the amplitude of the deviation curve is rather small, we

can still see from Fig. 5 large frequencies of time intervals in a conspicuous manner at about 5 days, besides which we may observe three maxima of frequencies at abont 35, 75, and 105 days. This last period of 105 days was also seen in the world's destructive shallow earthquakes as already stated in a previous paper[3]. These identical results may be regarded as a clue to some hidden physical meaning to be unravelled by future investigations.

In conclusion, I wish to express my heartiest thanks to Prof. M. Ishimoto and to Dr. N. Miyabe, both of whom have given me many useful suggestions in the course of these studies.

15. 世界に於ける深層地震の分布

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1919 年より 1930 年に至る満 12 ケ年間に起つた世界に於ける深層地震の分布，特にその鉛直分布を調査して見た．

世界深層地震の週期性に就いても研究を試みた．

其の結果は次の通りである．

1. 世界に於ける淺層地震は地中海沿岸，亞細亞大陸，日本附近，フイリッピン群島附近，濠洲及びその附近の海底，北米，中米及び南米等廣範圍に分布してをるが，深層地震は之と異なつて地中海沿岸には全く起らない．又北米特にその大平洋沿岸には極めて稀にしか起らない．
2. 震源の深さが 700 km といふ最も深い地震は日本附近，南米の中部，フイリッピン群島南部及び濠洲の東方海中に起つて居る．亞細亞大陸の深層地震は比較的淺いものが多い．
3. 地球半徑方向の震源移動に關しては，
   (*a*) 或る深さの層に地震が起るとその層の中で引き續いて起る場合が多い．
   (*b*) 400～500 km の層から 300～400 km の層には震源が移り易い．
   (*c*) 300 km 以下の層より 300～400 km の層へ又 400～600 km の層より 300 km 以下の層へは移動することが稀である．
4. 序でに 1924 年から 1935 年に至る満 12 ケ年間に關東地方に起つた有感地震について，鉛直方向に於ける震源移動を調べた結果は次の通りである．
   (*a*) 同一深さの層に於いて，地震は引續いて起り易い．特に 60～80 km の層に於いてその傾向が著しい．
   (*b*) 20 km以下の層から 20～40 km の層へ又 80 km 以上の層から 60～80 km の層へは震源が移り易い．

3) S. YAMAGUTI, *loc. cit.*, 2), 59.

(*c*) 20 km 以下の層から 60～80 km の層へ又その反對の 60～80 km より 20 km 以下の層へは移動することが稀である．卽ちその二つの層は，地震が相次いで起ることに關してお互に無關係である．

5. 世界深層地震の週期性については，175 日と云ふ週期が出て來るが，之は V. Conrad が著者とは異なつた方法で調べられた結果指摘されて居るところの半年週期に相當する．

105 日と云ふ週期も表はれて居るが，この週期は世界の破壞的淺層地震にも共通であると云ふことは何か或る物理的意義を有するものと思はれる．

長岡博士は地軸變動の週期のhigher harmonics に相當するものではないかと云ふ疑問を懷いて居られる．何れ將來の研究を待つて其の意義が明瞭にされるものと思ふ．