27. *Deformation of the Rhombic Base Lines at Mitaka and Earthquake Frequency in Kwantô Districts.*[1]

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The secular variation of the area of the rhombus formed by a set of five geodetic base lines, situated in the compound of the Tôkyô Astronomical Observatory at Mitaka, was already investigated fully by C. Tsuboi,[2] who suspected a possible connection between an abnormal change of this area and the occurrence of a severe earthquake. While dealing with the statistical data of the yearly frequencies of earthquakes in the Kwantô District, the present author happened to remark some trace of apparent relation between the said variation of the frequencies and the variation of the area of the rhombic base lines. An attempt was, therefore, made to investigate in some detail whether such a relation may exist actually.

For the data of the earthquakes to be taken for the basis of the statistical investigation, the List of the "conspicuous" and "rather conspicuous" earthquakes, compiled by Mr. Takami Isikawa[3] of the Central Meteorological Observatory, was utilized. As the List ends with 1925, the later data were taken directly from Kisyô-yôran up to 1931. From these data those earthquakes were picked out of which the epicentres are located in the Kwantô District, i. e. the Provinces of Musasi, Sagami, Awa, Kadusa, Simoosa, Kôduke, Simotuke and Hitati. To these were added those earthquakes originated in Idu, Kai and Iwaki, though the omission of these could scarcely affect the general qualitative feature of the results. Those earthquakes located in the sea area off the Pacific coast of the above district were also taken into account.

For the change of area of the base-line-rhombus, the mean value was taken of the increments of the areas of the two adjacent triangles composing the rhombus, observed during the interval between the two successive measurements. Thus, denoting the mean area by S, we cal-

1) An abstract of this paper is already published in *Proc. Imp. Acad.*, 8 (1932), 8.
2) C. Tsuboi, *Proc. Imp. Acad.*, 6 (1929), 367; *ibid.*, 7 (1931), 155.
3) T. Ishikawa, *Kensin-Zihô*, 2 (1926), 87.

culated $\Delta S/S=s$ for the successive intervals. On the other hand, the numbers n of earthquakes recorded during the corresponding intervals were to be counted and compared with the above s. The counting was made in the following three ways: (1) The number was counted regardless of intensity of the earthquake. (2) Those earthquakes were only counted of which the epicentres are located in the land area (including the Tokyo Bay and Uraga Channel). (3) The earthquakes were weighted according to intensities, namely with the weight 1 for the "rather conspicuous," 2 for the "conspicuous" and 3 for those severe ones accompanied with sensible destructive effects and casualities. Denote the numbers respectively by n_1, n_2 and n_3. The difference n_1-n_2 will practically give the number of earthquakes originated from the sea area. The time interval for counting the earthquakes was taken from the day on which the geodetic measurement at the beginning of the said interval was completed to the day on which the next measurement was closed. Table I (A) gives the data used for the comparison.

Table I. (A)

	Time Intervals from — to	No. of Days	s 10^{-5}	n_1	n_2	n_3	$\dot{s}$ 10^{-6}/100d.	$\dot{n}_1$ No./100d.	$\dot{n}_2$ No./100d.	$\dot{n}_3$ No./100d.	$\dot{n}_1-\dot{n}_2$ No./100d.
1.	1916. VI. 11—1917. II. 20	254	−0·045	26	6	33	−0·18	10·2	2·4	13·0	7·9
2.	1917. II. 20— 〃 . X. 17	239	+0·525	17	10	22	+2·20	7·1	4·2	9·2	2·9
3.	〃 . X. 17—1918. II. 10	116	−0·525	11	4	12	−4·53	9·5	3·5	10·3	6·0
4.	1918. II. 10— 〃 . X. 23	255	−0·050	18	8	23	−0·20	7·1	3·1	9·0	3·9
5.	〃 . X. 23—1919. XII. 12	415	+0·345	21	8	23	+0·83	5·1	1·9	5·5	3·1
6.	1919. XII. 12—1920. XI. 24	348	+0·330	23	7	29	+0·95	6 6	2·0	8·3	4·6
7.	1920. XI. 24—1921. XI. 8	349	+0·095	12	9	17	+0·27	3·4	2·6	4·9	0·9
8.	1921. XI. 8—1922. XI. 8	365	−0·215	26	19	39	−0·59	7·1	5·2	10·7	1·9
9.	1922. XI. 8—1923. IX. 6	302	+2·910	33	17	47	+9·64	10·9	5·6	15·6	5·3
10.	1923. IX. 6— 〃 . X. 24	48	−0·545	18	15	26	−11·36	37·5	31·3	54·2	6·3
11.	〃 . X. 24—1924. I. 29	97	−0·260	21	17	26	−2·68	21·7	17·5	26·8	4·1
12.	1924. I. 29— 〃 . VIII. 15	199	−0·345	27	16	32	−1·73	13·6	8·0	16·1	5·5
13.	〃 . VIII. 15—1925. XII. 17	487	+0·380	44	29	46	+0·78	9·0	5·9	9·4	3·1
14.	1925. XII. 17—1927. XII. 16	729	+0·935	37	12	39	+1·28	5·1	1·7	5·4	3·4
15.	1927. XII. 16—1929. III 20	460	−0·195	13	6	16	−0·42	2·8	1·3	3·5	1·5
16.	1929. III. 20—1930. II. 14	331	−0·470	9	3	12	−1·42	2·7	0·9	3·6	1·8
17.	1930. II. 14—1931. X. 6	599	+0·360	28	12	42	+0·60	4·7	2·0	7·0	2·7

Table I (B). For the meaning of n''s and n'''s see later.

Time Interval No.	n_1'	n_2'	n_3'	$\dot{n}_1'$	$\dot{n}_2'$	$\dot{n}_3'$	n_1''	n_2''	n_3''	$\dot{n}_1''$	$\dot{n}_2''$	$\dot{n}_3''$
1	22	4	28	8·7	1·6	11·0	22	4	30	8·7	1·6	11·8
2	19	10	25	8·0	4·2	10·5	18	4	23	7·5	1·7	9·6
3	9	6	9	7·8	5·2	7·8	10	6	14	8·6	5·2	12·1
4	19	7	25	7·5	2·7	9·8	22	10	24	8·6	3·9	9·4
5	22	8	24	5·3	1·9	5·8	24	11	29	5·8	2·7	7·0
6	25	8	31	7·2	2·3	8·9	26	7	32	7·5	2·0	9·2
7	12	9	17	3·4	2·6	4·9	14	8	20	4·0	2·3	5·7
8	24	17	37	6·6	4·7	10·1	18	15	27	5·9	4·1	7·4
9	25	11	28	8·3	3·6	9·3	22	14	27	7·3	4·6	8·9
10	15	11	31	31·3	22·9	64·6	0	0	0	0·0	0·0	0·0
11	26	21	31	26.8	21·6	32·0	13	3	15	13·4	3·1	15·5
12	31	23	38	15·6	11·6	19·1	53	43	78	26·6	21·6	39·2
13	46	29	49	9·4	6·0	10·1	56	36	61	11·5	7·4	12·5
14	38	14	40	5·2	1·9	5·5	36	15	37	4·9	2·1	5·1
15	12	6	14	2·6	1·3	3·0	21	9	24	4·6	2·0	5·2
16	10	3	14	3·0	0·9	4·2	12	3	16	3·6	0·9	4·8
17	25	10	36	4·2	1·7	6·0	18	7	24	3·0	1·2	4·0

At first, the values of s, n_1, n_2, n_3 were respectively plotted as ordinates against the time as abscissa, taking the middle points of the successive intervals as the corresponding time. Some apparent positive correlation was noted between s and n's. It must, however, be taken into consideration that s as well as n's represent the total increments for the common interval of time, so that when the intervals are not constant the above graph will merely serve for the comparison of $ds/dt.\Delta t$ with $dn/dt.\Delta t$, but not of ds/dt with dn/dt. On plotting Δt curve, it may be seen that the above apparent correlation is utterly illusory.

In comparing the time rates of s and n with each other, some difficulty is felt, since the intervals are rather irregular. Disregarding this irregularity, however, ds/dt and dn/dt were estimated by dividing the above values of s and n by the number of days in the corresponding interval. The graphs of these time rates are plotted in Fig. 1, in which the ds/dt curve is drawn inverted. In order to discuss the possible relation between the two quantities ds/dt and dn/dt, the following

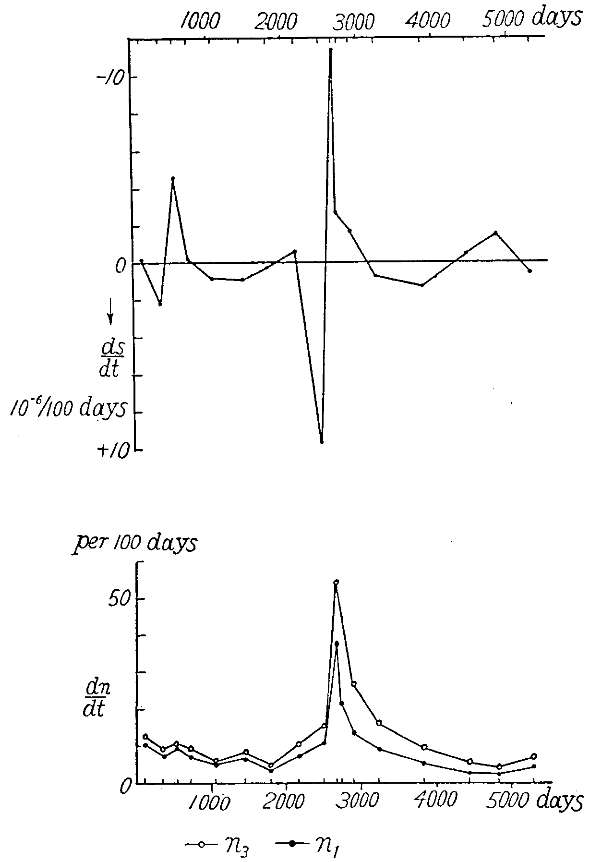

Fig. 1.

graphical method was employed. Taking $dn/dt=\dot{n}$ and $ds/dt=\dot{s}$ respectively as abscissa and ordinate, the points are successively plotted for the successive intervals and the consecutive points are connected by a straight line marked by arrow showing the time sequence. If a positive or negative correlation prevailed between the two quantities these straight lines will show a tendency to make acute or obtuse angle respectively with the positive direction of x. Besides, if there existed some systematic time-lag between the two quantities the successive arrows will show a tendency to be gradually deflected either in clockwise or counter-clockwise sense.

Such diagrams were constructed and the numbers of cases with the positive and negative correlations, as well as of those with the clockwise and opposite rotations were respectively counted for each of $\dot{n}$'s. Fig. 2 illustrates the diagram for the case of n_3. The results of statistics are summarized in Table II (A).

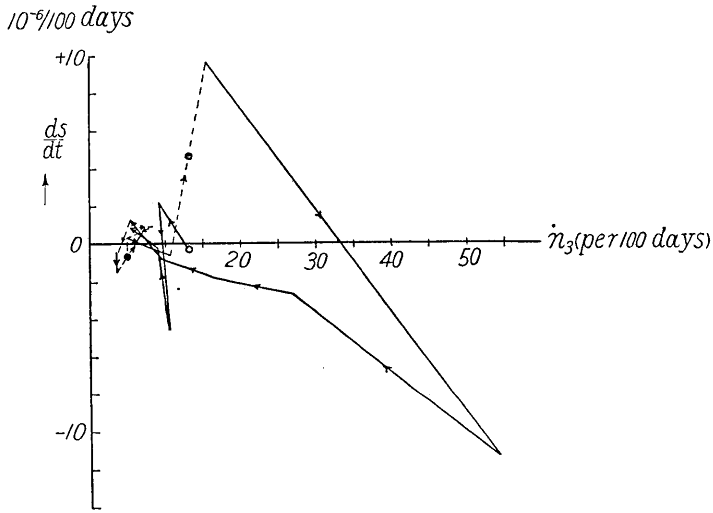

Fig. 2. Broken lines start from ○. ● marks the cases in which both $\dot{n}_3$ and $\dot{s}$ increased.

Table II. (A)

Correlation	$\dot{n}_1$	$\dot{n}_2$	$\dot{n}_3$	$\dot{n}_1-\dot{n}_2$
Negative	10	9	11	9
Positive	6	7	5	7
Counter-clockwise	10	10	9	8
Clockwise	5	5	6	7

(B)

Correlation	$\dot{n}_1'$	$\dot{n}_2'$	$\dot{n}_3'$	$\dot{n}_1'-\dot{n}_2'$
Negative	10	11	10	9
Positive	6	5	6	7
Counter-clockwise	10	6·5	10	10
Clockwise	5	8·5	5	5

(C)

Correlation	$\dot{n}_1''$	$\dot{n}_2''$	$\dot{n}_3''$	$\dot{n}_1''-\dot{n}_2''$
Negative	7·5	8	8·5	7
Positive	8·5	8	7·5	9
Counter-clockwise	10	10	9	8
Clockwise	5	5	6	7

(The case in which the sense of correlation or rotation is indeterminate, is counted as 0.5 for each of the two alternatives.)

It will be seen that the negative correlation is most conspicuous in the case of $\dot{n}_3$. The counter-clockwise rotations predominate in the case of $\dot{n}_1$ and $\dot{n}_2$, which suggests that the variation of $\dot{s}$ lags after that of $\dot{n}$'s. Referring to Fig. 2, in which the negative and positive correlations are respectively represented by the full and dotted lines, it may be remarked that there are only two cases in which both the quantities $\dot{s}$ and $\dot{n}_3$ underwent simultaneous increases, as are indicated by • marked upon the corresponding dotted arrows. The Great Kwantô Earthquake and the recent N. Idu Earthquake occurred respectively in the intervals of time represented by these two arrows. It is difficult at present to decide whether this fact of singular coincidence is due to a mere accident or not. The coincidence is still too striking to be cast off as utterly trivial without a further inquiry.

Instead of comparing $\dot{s}$ and $\dot{n}$'s in the corresponding time intervals the time for the earthquakes was taken one month earlier than that for $\dot{s}$; for example, s in the interval 11 June 1916—20 Feb. 1917 was made to correspond with n for 11 May 1919–20 Jan. 1917. We denote these numbers of earthquakes by n''s which are tabulated in Table I (B). The result of the similar statistics is shown in Table II (B).

Similarly the epochs for n's were taken six months earlier than those for s. Denoting the corresponding n and dn/dt for this epoch by n'' and $\dot{n}''$ which are tabulated in Table I (B), the relation between the variations of $\dot{s}$ and $\dot{n}''$ is summarized in Table II (C).

It will be seen that in Table II (B) for n', the negative correlation is preserved and even improved a little for n_2, for which the apparent time-lag has disappeared. In Table II (C), the negative correlation has entirely been obliterated, while the apparent time-lag remains for n_1'' and n_2''.

From these results, it may be concluded that there exists at least some traces of relation between the variations of $\dot{s}$ and $\dot{n}$ here considered. It seems (1) that generally $\dot{s}$ decreases with the increased $\dot{n}$ and (2) that the variation of $\dot{s}$ lags a little behind that of $\dot{n}$.

On the other hand, the semi-annual numbers of earthquakes were counted as shown in Table III, from which the mean values for the successive two half-years were taken and plotted in Fig. 3, together with the inverted $\dot{s}$ curve.

Table III.

Time Interval		No. of Eqks.			Time Interval		No. of Eqks.		
		n_1	n_2	n_3			n_1	n_2	n_3
1916	VII–XII	17	4	22	1924	I–VI	29	18	36
1917	I–VI	15	5	22	〃	VII–XII	22	14	25
〃	VII–XII	15	11	15	1925	I–VI	19	12	19
1918	I–VI	14	4	18	〃	VII–XII	10	7	10
〃	VII–XII	9	4	11	1926	I–VI	11	5	11
1919	I–VI	11	5	12	〃	VII–XII	7	2	8
〃	VII–XII	11	3	15	1927	I–VI	7	1	7
1920	I–VI	15	4	19	〃	VII–XII	13	4	14
〃	VII–XII	10	6	15	1928	I–VI	6	8	8
1921	I–VI	7	5	8	〃	VII–XII	3	3	3
〃	VII–XII	3	3	6	1929	I–VI	8	11	11
1922	I–VI	17	13	27	〃	VII–XII	2	3	3
〃	VII–XII	10	6	10	1930	I–VI	9	11	11
1923	I–VI	20	7	23	〃	VII–XII	5	8	8
〃	VII–XII	42	33	64	1931	I–VI	8	13	13

Though it will be premature to presume a theoretical discussions of the present result based on such a scanty data, the following considerations will be of some interest at least in way of a suggestion. Two alternatives may be proposed regarding the possible relation between s and n, as far as they are not in contradiction with the present results, i. e.

$$\frac{dn}{dt}-f(t)+k\frac{ds}{dt}=0, \tag{1}$$

$$\frac{d}{dt}\left\{\frac{dn}{dt}-\phi(t)\right\}+k'\frac{ds}{dt}=0, \tag{2}$$

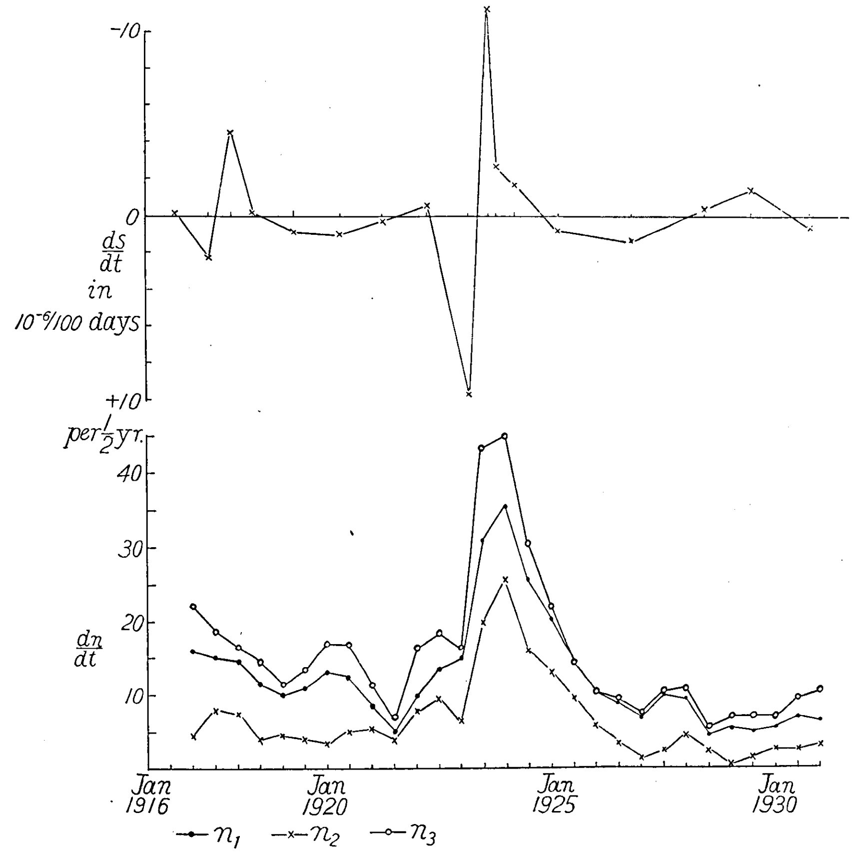

Fig. 3.

where $f(t)$ and $\phi(t)$ are slowly varying functions of time, and k and k' positive constants. From these we obtain respectively

$$k(s-s_0)=\int_0^t f(t)dt-n, \tag{1'}$$

$$k'(s-s_0)=ct+\int_0^t \phi(t)dt-n, \tag{2'}$$

where s_0 and c are constant. Provided with a sufficiently abundunt data, it seems possible to undertake a statistical test of such a relation and even to determine the form of $f(t)$ or $\phi(t)$.

At any rate, it seems that the area of the rombus is subjected to a gradual secular expansion owing to some straining force continuously acting on the part of the earth's crust on which it is situated. On the other hand an earthquake seems to have an influence to check, or oppose to this expansion. It is not difficult to conceive a mechanical model to illustrate such a behaviour. Consider, for example, an end of a caoutchouc band is fixed to a sheet of paper at one of its corners, while another corner is held fixed. Let the paper be provided with an initial cut which may easily grow under a suitable tension applied to the paper. Pulling the other end of the caoutchouc band with a constant velocity, the band will be at first extended but then tend to contract as the paper is torn little by little. As the tearing of the paper is irregularly rhythmical, the band will also be extended and contracted with irregular periods.

In the above statistics no account was taken of the distance of the epicentres from the base line in question. It seems plausible to assign a suitable "weight" to each earthquake according to a decreasing function of distance, besides the weight due to the intensity of the earthquake for which a tentative values were assumed for obtaining n_3 above defined. The azimuth of the epicentre comes next into consideration, as it is probable that the effect of an earthquake upon the deformation of the rhombus may depend much on the direction of the origin as well as on its distance. The materials at hand seems however still too scanty for allowing us to enter upon such detailed studies.

A serious drawback felt in the present investigation is that the measurements of the rhombus are made in too much irregular intervals. It is highly desirable that the measurement will be repeated with more regularity and if possible with a little shorter interval, six months say.

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27. 三鷹村菱形基線の變形と關東地方に於ける地震頻度との關係

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三鷹菱形基線によつて圍まれた面積の變化速度と、關東地方に於ける顯著な地震の頻度との間の統計的關係を調査した結果、兩者の間に多少の相關が存在することを確めることが出來た。面積は地震のない時は增大する傾向があるが、地震があるとそれが減ずるやうな傾向がある。なほ、偶然かも知れないが、關東地震の時と北伊豆地震の時と、此の二つの場合に相當する期間に限つて、面積變化速度と地震頻度との關係の異常が認められる。
