Note on the Relation between Earthquakes and Changes in Latitude.

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With Plates V and VI.

1. *Introduction.* The relation between earthquakes and changes in latitude is one of the subjects whose investigation was undertaken by the Imperial Earthquake Investigation Committee,[1] which instituted in 1895 the observation of latitude variation in Tokyo by means of a Wanschaff's zenith telescope of 81 mm aperture.[2]

I give next a short account of what has already been done by seismologists in this connection, and then proceed to compare the seismic frequency in Japan with changes of latitude in Tokyo.

2. In the British Association Report for the year 1900, Prof. Milne gives, for the years 1895 to 1898 inclusive, a comparison of the wanderings of the pole from its mean position with the registers of earthquakes which have disturbed the whole world, or, at least, continental areas; the conclusion arrived at being that when the pole displacements were comparatively great large earthquakes were frequent and *vice versa*. Prof. Milne's results are as follows.

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1) See Baron Kikuchi's Preface to No. 1 of the *Publications*; also No. 1 of the Reports (Japanese), published in 1893.

2) In 1898, the work of the latitude observation in Tōkyō has been transferred to the Imperial Geodetic Commission. The observations were made first by Dr. H. Kimura, and subsequently by Mr. K. Hirayama.

Year	Total latitude variation.	Number of large earthquakes.
1895	0".53	9
1896	0".91	18
1897	1".07	44 or 47
1898	1".03[1]	30

Prof. Milne's investigation was continued by Dr. A. Cancani, who obtained, for the years 1899 to 1902 inclusive, the following results.[2]

Year.	Total latitude variation.	Number of large earthquakse.
1899	0".72	27
1900	0".32	17
1901	0".53	22
1902	0".97	29

The inference to be drawn from the above table is similar to that already obtained by Prof. Milne, namely, that the total annual amount of the latitude variation was greater or smaller according as the number of large earthquakes was large or small.

In the British Association Report for the year 1903, Prof. Milne examines the numbers of large earthquakes in the ten parts, into which each of the years, 1892 to 1899, is divided; the results of the investigation being that this same type of earthquakes has been frequent when the change in direction of the movement of the pole has been marked.

§ 3. *Latitude variation at Tokyo.* The following table gives the mean monthly values of the latitude of Tokyo (the Astronomical Observatory) for nearly 8½ years between Aug. 1895 and Dec. 1903; the results being graphically illustrated in fig. 1.

1) Adopting the value corrected by Dr. A. Cancani.

2) Dr. A. Cancani: Sopra un' ipotetica relazione fra le variazioni di latitudine e la frequenza dei terremoti mondiali. Boll. della Soc. Sism. Italiana, Vol. VIII.

RESULTS OF LATITUDE OBSERVATIONS AT TOKYO.

AUG. 1895—DEC. 1903.

Mean date.	Decimal of the year.	Latitude.	Mean date.	Decimal of the year	Latitude.
1895 Aug. 12	1895.61	35°39′16″59	1900 Apr. 18	1900.30	35°39′16″84
Sept. 14	70	16.71	May 13	37	16.81
Oct. 18	80	16.72	June 13	45	16.82
Nov. 16	88	16.81	July 26	57	16.81
Dec. 15	96	16.80	Aug. 15	62	16.76
1896 Jan. 32	1896.06	16.75	Sept. 18	72	16.79
Feb. 12	12	16.73	Oct. 15	79	16.88
Mar. 16	21	16.68	Nov. 15	87	16.82
Apr. 13	28	16.60	Dec. 12	95	16.79
May 16	37	16.57	1901 Jan. 16	1901.05	16.76
June 15	46	16.47	Mar. 23	23	16.70
Sept. 20	72	16.69	Apr. 13	28	16.70
Oct. 19	80	16.83	May 18	38	16.69
Nov. 12	87	16.84	June 16	46	16.67
Dec. 12	95	16.87	July 26	57	16.69
1897 Jan. 13	1897.07	16.85	Oct. 22	1901.81	16.98
Feb. 13	12	16.85	Nov. 22	89	17.04
Mar. 16	21	16.78	Dec. 14	95	17.01
Apr. 23	31	16.77	1902 Jan. 13	1902.04	16.98
May 19	38	16.59	Feb. 15	13	16.85
June 13	45	16.52	Mar. 13	20	16.83
July 18	55	16.41	Apr. 16	29	16.67
Aug. 17	63	16.39	May 16	37	16.64
Sept. 15	71	16.54	June 10	44	16.62
1898 Oct. 15	1898.79	16.58	July 13	53	16.67
Nov. 12	87	16.78	Aug. 28	66	16.86
Dec. 14	95	16.88	Sept. 18	72	16.92
1899 Jan. 19	1899.05	16.95	Oct. 16	79	16.95
Feb. 11	12	16.94	Nov. 15	88	17.02
Mar. 20	22	17.02	Dec. 19	97	17.03
Apr. 18	30	17.02	1903 Jan. 15	1903.04	17.04
May 15	37	16.95	Feb. 15	13	16.92
1899 June 12	1899.45	16.85	Mar. 13	20	16.85
July 21	55	16.66	Apr. 16	29	16.75
Aug. 17	63	16.60	May 16	37	16.61
Sept. 13	70	16.61	June 13	45	16.54
Oct. 18	80	16.68	July 22	56	16.53
Nov. 15	87	16.67	Aug. 20	64	16.56
Dec. 24	98	16.69	Sept. 15	71	16.61
1900 Jan. 21	1900.06	16.73	Oct. 16	79	16.69
Feb. 16	13	16.77	Nov. 13	87	16.77
Mar. 17	21	16.81	Dec. 17	96	16.89

To see the relation, if any, between the latitude variation in Tokyo and the frequency of large Japan earthquakes, the latter are marked along the abscissa or time axis of the diagram (fig. 1); each black dot (•) denoting a great and more or less destructive shock, while a small circle (o) denotes a large earthquake which was not destructive, but whose area was extensive and about 10,000 square *ri*[1] or more.

An examination of fig. 1 shows that all the destructive earthquakes occurred exactly or very nearly at those epochs when the latitude was at a maximum or a minimum. The non-destructive extensive earthquakes indicate also a similar tendency, though in a less marked degree.

Note. From fig. 1 it will be at once observed that the curves b and c and the curves b' and c' are nearly symmetrical with respect to the curve a; b and c correspond to the epoch June 1901 to June 1903, c' and b' to the epoch Aug. 1897 to Aug. 1899, while a corresponds to the epoch Aug. 1899 to June 1901. The latitude variation was smallest in the epoch denoted by the curve a.

The following table contains a list of the successive epochs of the different phases of the latitude variation, deduced directly from the diagram (fig. 1), each sign (×) denoting a destructive earthquake. It will be seen that all the destructive earthquakes occurred during the epochs of the maximum and minimum latitude, as above stated.

Minimum Latitude.	Maximum Latitude.	Decreasing Latitude.	Increasing Latitude.
Year. Month.	Year. Month.	Year. Month.	Year. Month.
1896, VI–VIII. ××	1895, XI–XII.	1896, I–V.	1895, VIII–X.
1897, VII–VIII. ×	1896, X–1897, II. ×	1897, III–VI.	1896, IX.
1898, IX. ×	1899, I–V. ××	1899, VI.	1898, X–XII.
1899, VII–XII.	1900, IV–XI. ×	1901, I.	1900, I–III.
1901, II–VIII. ×××××	1901, X–1902, I. ×	1902, II–III.	1901, I–X.
1902, IV–VII.		1903, II–V.	1902, VIII–X.
1902, XI–1903, I.			1903, IX–XII.
1903, VI–VIII.			
Aggregate duration =26 months.	Aggregate duration =16 months.	Aggregate duration =14 months.	Aggregate duration =14 months.

1) 1 *ri* = 4 km nearly.

4. *Sensible earthquakes in Tokyo.* The total numbers of the *sensible* earthquakes in Tokyo, which occurred during the different phases of the latitude variation, between 1895 and 1903, were as follows:—

With minimum latitude	111	earthquakes.
„ maximum „	69	„
Sum	$=E_1=180$	„
With decreasing latitude	76	„
„ increasing „	47	„
Sum	$=E_2=123$	„

These figures apparently indicate that the earthquakes of the kind under consideration occurred most frequently with the minimum latitude and least frequently with the increasing latitude. In reality, however, such was not the case. Thus the total numbers of the months included under the different phases were as follows:—

Minimum latitude	26	months
Maximum „	16	„
Sum	$=S_1=42$	„
Decreasing latitude	14	„
Increasing „	14	„
Sum	$=S_2=28$	„

The ratios $\frac{E_1}{S_1}$ and $\frac{E_2}{S_2}$ are practically identical, being respectively 4·3 and 4·4; a result which seems to indicate that the frequency of the sensible esrthquakes in Tokyo has no relation to the latitude variation.

5. *Earthquakes of area greater than 1000 square ri.* The numbers of recent Japan earthquakes of land area of disturbance[1] greater than 1000 square *ri*, which happened during the different phases of

1) "Area of disturbance" of an earthquake means here the area within which the shaking was felt, or strong enough to be perceptible without instrumental aid.

the latitude variation, between 1895 and 1903, were as flollows:—

With minimum latitude	49	earthquakes.
,, maximum ,,	29	,,
Sum $=E_1'=78$		,,
With decreasing latitude	36	,,
,, increasing ,,	18	,,
Sum $=E_2'=54$		,,

The preponderance of the earthquakes in the epochs of the maximum and minimum latitude is here again only apparent; the total numbers of the months included under the different phases being as follows:—

Minimum latitude	12	months.
Maximum ,,	12	,,
Sum $=S_1'=24$		,,
Decreasing latitude	10	,,
Increasing ,,	7	,,
Sum $=S_2'=17$		,,

The ratios $\frac{E_1'}{S_1}$ and $\frac{E_2'}{S_2'}$ are equal to one another, being 3.3 and 3.2 respectively.

6. From what has been said in §§ 4 and 5, it seems that great destructive earthquakes in Japan have a marked tendency to occur in the epochs of the maximum and minimum latitude at Tokyo, a conclusion which is in harmony with the results already obtained by Prof. Milne (§ 2). On the other hand, the frequency of the small earthquakes or those whose areas of disturbance is, say, under 10,000 square *ri*, seems to have no particular relation to the latitude variation.

7. *Note on the long-period variations of seismic frequency.*

(*a*) Destructive earthquakes in Japan. Great seismic disturbances

happen sometimes singly or isolated but generally tend to occur in groups. Thus the 154 destructive earthquakes in Japan since the beginning of the 14th century may be more or less definitely divided into 41 groups, whose mean epochs recurred, on average, every $13\frac{1}{3}$ years.

(*b*) *Earthquakes in Kyōto.* Kyōto was the capital of the Empire during the 1070 years between 797 and 1867. The record of earthquakes in this city is therefore most complete, and includes 1318 shocks, of which 34 were destructive, 194 *strong*, and the remaining 1090 *slight*. Confining our attention to the two most disturbed epochs, namely, the 9th century and the time interval between the years 1340 and 1609, the seismic *activity*[1] presents a series of fluctuations of periods, whose mean value is $6\frac{1}{2}$ years. Especially between the years 854 and 890 the variations were regular and had an average period of 6 years.[2] (See fig. 2.)

In connection with the periodicities of the seismic activity above considered it is interesting to note that, according to Dr. H. Kimura, who studied the latitude variation during the intervals between the years 1890 and 1902, the polar motion has a six years' period, the maximum deviations of the instantaneous pole having occurred in 1891 and 1897, and the minimum in 1894 and 1900.[3]

The mean period of seismic activity at Kyōto is thus equal to that of the pole motion, while the mean epochs of the destructive earthquakes recur at intervals of nearly double the length.

8. *Earthquakes in Japan between 1885 and 1903.* For the sake of reference I give in the following table the numbers of earthquakes in the whole of Japan during the 19 years between 1885 and 1903, classified according to the land area of disturbance, and also to the

1) *Seismic activity* for each year is here the sum of the numbers of small, strong, and destructive earthquakes multiplied respectively with the coefficients 1, 2, and 2.

2) F. Omori: Notes on the Earthquake Investigation Committee Catalogue of Japanese earthquakes. Jour. Sc. Coll., Tōkyō Imp. Univ., Vol. XI.

3) H. Kimura: On the Six years' cycle of the polar motion during the interval 1891–1902. Astr. Nachr., No. 3932, Feb. 1904.

intensity[1] of motion at the epicentre or at the nearest sea-coast in cases the latter was submarine. Some of the *slight* earthquakes were unfelt ones, which were, however, intense enough to be registered by ordinary Gray-Milne type seismographs.

JAPAN EARTHQUAKES IN RECENT YEARS.

Year.	Land area of disturbance. (in square *ri*)					Intensity.			Sum.
	<100	>100	>1,000	>5,000	>10,000	Strong.	Weak.	Slight.	
1885	309	143	28	2	0	—	—	—	482
1886	349	104	18	1	0	—	—	—	472
1887	349	97	34	3	0	—	—	—	483
1888	482	104	41	3	0	58	266	306	630
1889	767	117	44	2	0	51	290	589	930
1890	707	96	39	3	0	49	264	532	845
1891	1875	628	157	9	1	84	332	2164	2670
1892			26	4	0	85	242	1591	1918
1893			27	2	0	49	220	1267	1536
1894			25	12	5	65	335	2329	2726
1895			10	4	1	28	189	1200	1417
1896			15	20	3	56	273	1578	1907
1897			9	21	6	29	209	1493	1731
1898	1280	235	45	15	3	37	226	1384	1647
1899	1389	243	30	12	7	40	153	1562	1755
1900	1496	237	130	20	5	45	200	1643	1888
1901	1278	251	132	20	6	34	215	1361	1610
1902	1177	220	113	20	3	37	184	1267	1488
1903	1051	184	99	11	3	43	175	1131	1349

1) The *intensity* of non-destructive earthquakes is indicated as *strong*, *weak*, or *slight*. A *slight* shock is one which is very feeble and just sensible; a *weak* shock is one whose motion is well pronounced but not so severe as to cause general alarm; and finally a *strong* shock is one which is sufficiently severe to knock down some furniture, to cause people to run out of doors, etc

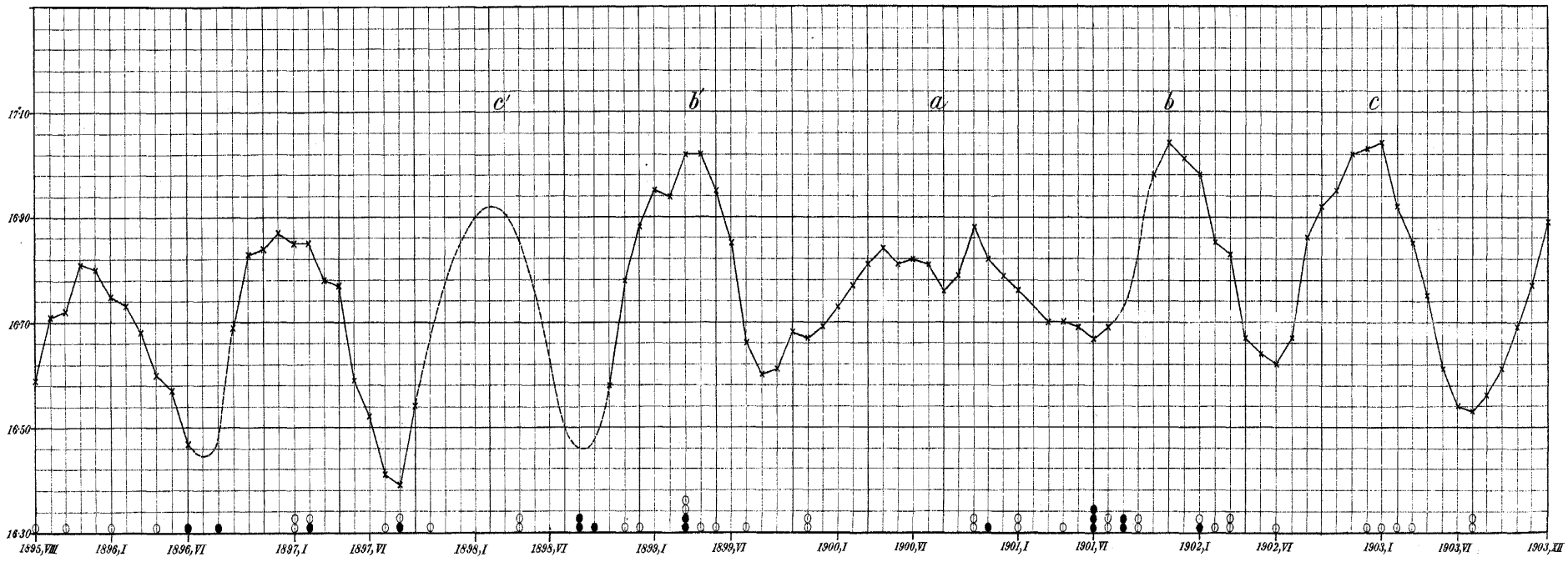
With respect to the above table, two things are to be remarked, namely, (1), that an enormous increase of earthquakes since 1891 is due to the after-shocks of the great earthquakes which took place in that and the subsequent years; and, (2), that a marked increase in the number of the earthquakes of area greater than 1000 square *ri* since 1900 is mainly due to the recent increase of the Gray-Milne type seismographs in the different parts of the country and to the consequent enlargement of the *area* of disturbance.

As stated before, the maximum deviations of the polar motion took place in 1891 and 1897, and also probably in 1903; and it is interesting to remark in this connection that the great Mino-Owari earthquake occurred in 1891, and the greatest number of earthquakes of land area larger than 5,000 square *ri* occurred in 1897, although the seismic activity was small in 1903.

A glance at the above table also indicates that the number of strong earthquakes (which include also violent and destructive ones) is not necessarily proportional to that of large earthquakes or those of great area of disturbance.

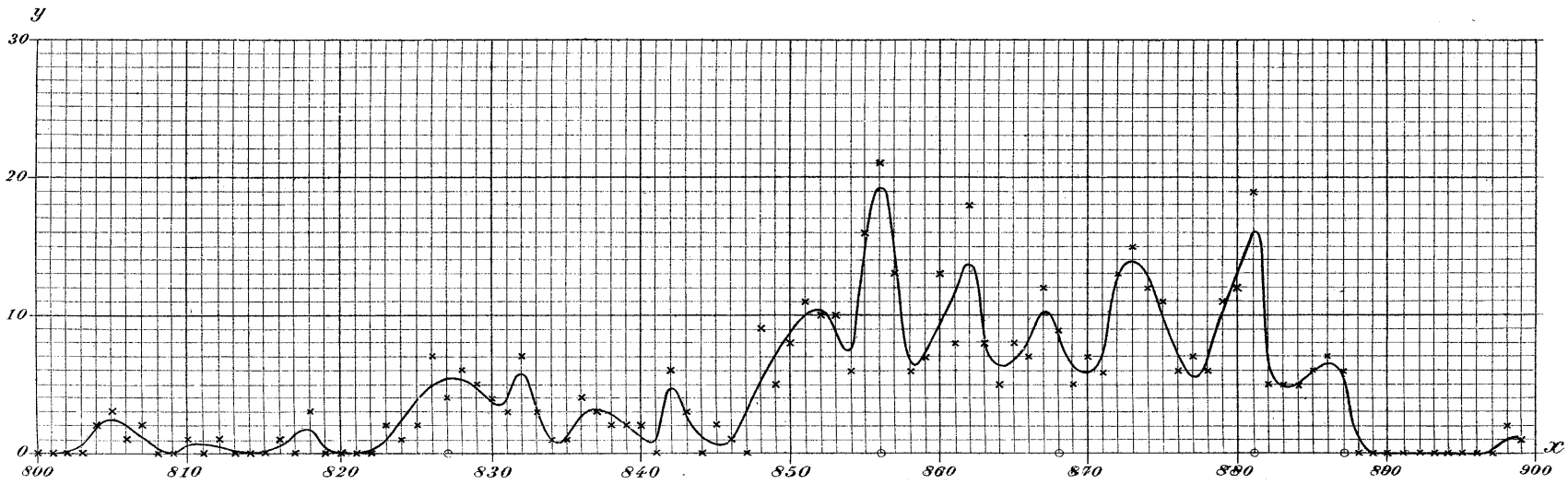
Tokyo. Aprii, 1904.

Fig. 1. Latitude Variation in Tokyo, between Aug. 1896 and Dec. 1903.



A black dot (•) along the abscissa axis denotes a destructive earthquake.
A small circle (○) along the abscissa axis denotes an earthquake, which was not destructive, but whose land area of disturbance was over 10,000 sq. *ri*.

Fig. 2. Seismic activity in Kyoto during the 9th century.



x=Time in years. y=Yearly seismic activity.

Each small circle (o) in the abscissa axis indicates a destructive earthquake in the year specified.