A Long Period Fluctuation in Latitude of the Seismic Activity on the Earth.(1)

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地球上に於ける地震活動地域平均緯度の長期移動

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地球上に於ける顯著地震の年表から、毎五十年間に起つた地震の地域の緯度の平均値を概算して、其の値の永年變化を調べて見た。此の統計を歐洲大陸、北米、中米、南米、支那、日本等に就き別々に行つて其結果を比較した。

第一圖に示した結果から、勿論餘り確實ではないが、大體次のやうな事が推測される。即ち、活動地域の平均緯度には二百年前後の程度の長週期をもつた移動がありさうに見える。而して各地方別の變化に多少の相關があるらしいから、此の週期は全然偶然の結果として棄てる事は出來ない。のみならず又上記の結果を、例へば地球自轉速度の永年變化と比較して見ると、多少の相關があるらしく見えるから、此處で想像された地震活動の緯度變化といふ現象には相當なプロバビリチーのあるものと考へなければならない。他のあらゆる方面からの研究を希望したい。

Many investigations have hitherto been made regarding the problem of periodicity of earthquakes. For the most part, however, the periodicity investigated is that of the variation of the frequency of earthquakes as a function of time, while the research concerning the time relation of displacement of seismic activity on the earth has been rarely made. Prof. Omori alluded, indeed, sometimes to an irregular fluctuation in the positions of the epicentres of severe earthquakes occurring successively on a distinct active zone, though he arrived at no definite conclusion on its periodicity. N. F. Drake from his investigation of Chinese earthquakes suggested the existence of a periodic displacement of the activity with a

(1) An abstract of the present note has already been given in Proc. Imp. Acad., 3 (1927), 275; the data have been revised and some correction made for the missed data.

period of about 600 years. His method is, however, connected with the problem of bringing into alignment numerous points scattered on a plane which is often liable to some arbitrary choice. Still, the possibility of such a periodic or irregularly cyclic displacement of the locality frequented by earthquake may scarcely be denied especially by those who have ever made some study on the chronological distribution of earthquakes. The "period" may well be irregular and there may coexist many periods, some long and other short.

Recently, we became incidentally aware of a rather remarkable fact that the epicentres of the following seven destructive earthquakes lie on a nearly straight line inclined about 10° against the parallel of latitude somewhere about 35°N:

Mino-Owari	1891	Kwantô	Sept. 2, 1923
Anegawa	1909	Tazima	1925
Ooigawa	1917	Tango	1927
Kwantô	Sept. 1, 1923		

As a matter of fact, a number of earthquakes are recorded in other parts of Japan during the course of the period above taken, so that the above fact alone may convey no physical significance. Again, on looking a little back in the chronological lists we find the epicentres of the following five severe earthquakes lying on a line, inclined about 20° against the parallel of latitude about one degree, to the north of the former line:

Kanazawa	1799	Sinano	1858
Zenkôzi	1847	Noto	1892
Tôkyô (Yedo)	1855		

Here also, earthquakes in other districts are not wanting in the same epoch, so that just the same objection may be raised here as in the case of Drake's method regarding the physical meaning of the alignment.

The above relation, accidental or not, was at least stimulating and suggested another method of a further study which may give some more insight into the problem. For a trial, we took the chronological lists

compiled by Prof. Imamura and published in "Rika-Nenpyô", 1927, whence all the most severe earthquakes[1] in the Eurasian continent were picked up, which occurred in 1900–26. For these earthquakes we estimated the approximate respective latitudes of the epicentres. As, in many cases, the accurate location of the epicentre is difficult even within a range of few degrees, the latitude evaluated may have generally no meaning other than a kind of very rough index number. We may perhaps have better rounded off the number to each five or ten degree. It is needless to say that the latitudes thus found for a given epoch are widely scattered in values; still, on plotting all the earthquakes in 1900–26 upon a latitude scale, we may remark a conspicuous clustering of the point at about 40°N. On the other hand, a similar statistics was carried out for the preceding epoch 1800–1900 and a maximum of frequency was found at about 35°N. As the conspicuous earthquakes in the Eurasian continents occurs mostly in the well known zone running E–W, the above change in latitude of the zone of maximum frequency may at least suggest an actual secular displacement of the most active zone from N to S in the said succeeding epochs.

The above result led us to take a step further and to investigate the secular fluctuation of the "mean latitudes of earthquakes," in the above sense of the words, and those for different parts of the earth separately. If the time-variation of this mean would show an apparent periodic fluctuation, the *possibility* of such period may be demonstrated. If, again, the fluctuation in different parts of the earth would show some correlation the reality of such a period may appear in some degree *probable*. If, on the other hand, the said fluctuation may show some similarity with the fluctuation of other cosmical phenomena which may theoretically be in some direct or indirect physical relation with the occurrence of earthquake, the probability may be more or less increased. Of course, it is difficult to draw from this kind of investigation any conclusion on the real nature of the fluctuation thus obtained, but it may at least reveal a faint image, so to speak, of what is actually taking place with regard to the secular dis-

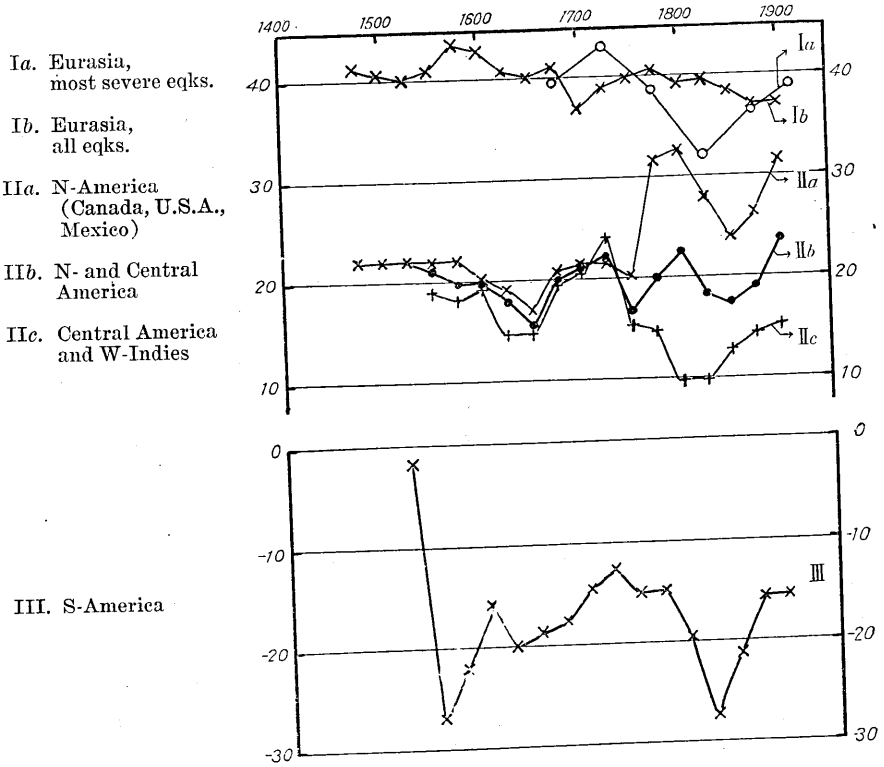
(1) Those were chosen of which more than 1000 casualities are reported. The arbitrary choice may be of some use in the present case of statistical investigation.

placement of the zone of activity, provided such thing exists. With these stand points clearly in view, the following may, we hope, be of some interest for many seismologists.

The materials for the further systematic investigation were also taken from the Lists above mentioned. The number of earthquakes recorded decreases necessarily as we go back with the date and, besides, the extent of the geographical area finding entry may also vary with time. All these difficulties are unavoidable, but must and may be taken as they are, when a rough investigation of some gross periodicity is in question, provided the said historical variation in the statistical basis is for the first approximation a continuous one, which may plausibly be assumed.

For the case of Eurasian continent the number of occurrence was large so that we could carry out the separate statistics for the "most

Fig. 1 a.



Ia. Eurasia, most severe eqks.

Ib. Eurasia, all eqks.

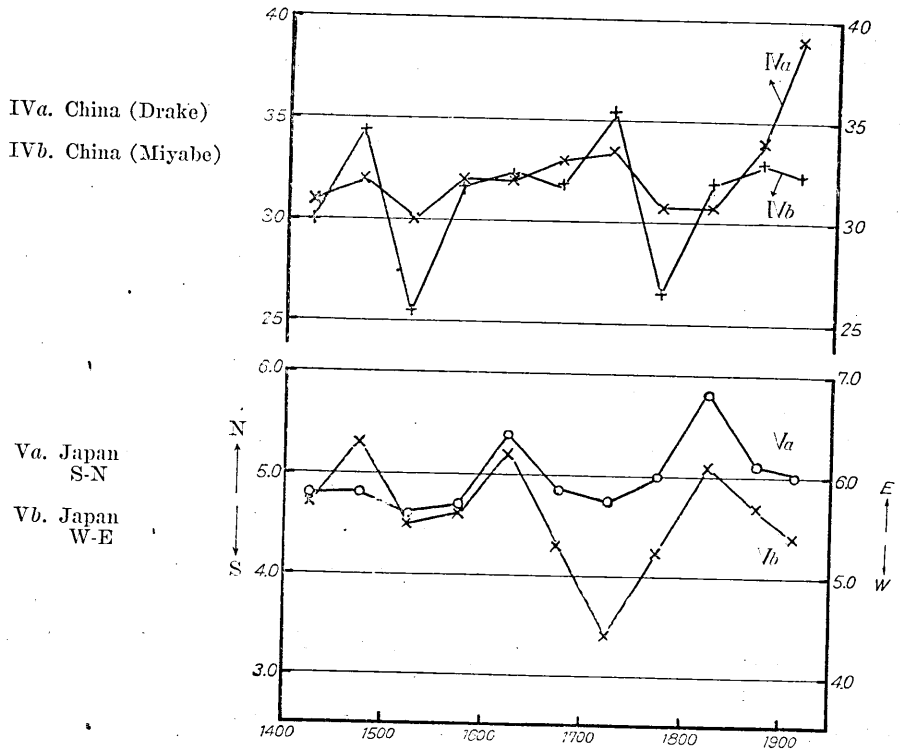
IIa. N-America (Canada, U.S.A., Mexico)

IIb. N- and Central America

IIc. Central America and W-Indies

III. S-America

Fig. 1 b.



severe earthquakes'' side by side with that for all the earthquakes recorded in the List.(1)

For the other parts of the earth, the following divisions were made:

North America including Mexico.

North America, Mexico and Central America.

Central America and West Indies.

South America.

The data for Chinese earthquakes were taken directly from Drake's paper in which the chronological sequence of earthquakes in separate Provinces are tabulated. We estimated roughly the latitude of the centre of area

(1) The earthquake which occurred within ten years after a severe earthquake in the same district was omitted in the present statistics.

of each Province and then calculated the mean latitude of foci for successive epochs of 50 years each.

The results are plotted in Fig. 1. For the "most severe" earthquakes in Eurasian Continent, I*a*, and the Chinese earthquakes, IV, the means for successive 50 years are given, while for the other cases overlapping 50 years means proceeding with 25 years step are plotted.

Referring to I*a* and I*b*, it may be noticed that the relation is quite different for the most severe earthquakes and for all earthquakes in the List. Such a relation has often been demonstrated by Prof. Omori with regard to Japanese earthquakes and it is interesting to observe a similar relation also appearing here in the data covering the whole continent. For the comparion with the different other regions we must therefore take I*b*, since for the other regions the means are taken of all the earthquakes.

Comparing I*b*, II*a*, II*c* and III with each other, we may notice the graph I*b* for Eurasian Continent shows some similarity with that of N. America including Mexico, while the curve for Central America and West Indies suggests a parallelism with that for S. America. Again, the first pair taken as a whole shows more or less reversed course of variation when compared with the latter pair. II*b* shows of course the mixed influence of II*a* and II*c*. Taking all the curves together a period of some 200 years may be suspected.

Curve IV for Chinese earthquakes shows more resemblance with I*a* or III than with I*b* with which it may be expected to be related. The matter is, therefore, not simple even if the suspected periodicity be real. Still, it may be well possible that a part of continent show an alternative time variation with the entire continent.

On the other hand, a somewhat different method of estimating the variation in position of activity was chosen for the case of historical earthquakes in Japan, which was found most suitable in view of the nature of the data at hand. Thus, the entire region was divided into a net of longitude and latitude with 2.5° mesh. The meshes were numbered 1–10 northwards from 25°N. and 1–8 eastwards from 125°E. This number was taken as an index number for roughly determining the latitude or longitude

of each epicentrum and the mean index number was calculated for each 50 years period. The results are shown in Curves V*a* and *b*.[1] The curves suggest again a period of 150–200 years. Comparing I*b* and V*a* we notice that the Japanese earthquake activity is rather sympathetic with the continental.[2]

Apparent parallelism between V*a* and V*b* may be mainly due to the fact that the Islands of Japan is elongated in the direction SW–NE. On the other hand, one of the authors, N. Miyabe, made an investigation[3] of the fluctuation in position of destructive earthquakes in China, taking the material from the Lists given in "Rika-Nenpyô" as IV*b*. The curve for the latitude-variation obtained shows some similar feature with IV*a* based on Drake's data as is expected. On the other hand, the latitude variation (Fig. 1, IV*b*) obtained by Miyabe shows some remarkable positive correlation with the longitude variation, a fact which means that in China also the displacement of the activity occurs in the direction SW–NE. Moreover, Miyabe's graphs for the latitude and latitude variations in China show some points of agreement with those for Japan. Miyabe also showed that the variation in the frequency of earthquakes shows inverted course for N. and S. China which is in accord with the fact of the latitude variation.

The fluctuations of the mean latitude of seismic activity above described are rather irregular and it will be premature to draw any definite conclusion from such a material. It may, however, not be also denied that there are some points of regularity among these variations. Especially, the parallelism among I*b*, II*a* and V*a* and the inverted course of III may not be hastily passed over as merely accidental, as the former refers to the N. hemisphere while the latter stands for the S. hemisphere.

Leaving the result of statistics as it is, we may now seek after a similar

(1) In Fig. given in the abstract published in Proc. Imp. Acad., loc. cit., the numbers on the right side of the curves are wrong; 4, 5, 6 are to be read 7, 6, 5 for S-N and 6, 5, 4 for W-E direction. The present Fig. is inverted so that N is on the upper side.

(2) The discrepancy remarked in the abstract cited now disappears when we take I*b* for comparion, which is more plausible than I*a* to take.

(3) N. Miyabe, Proc. Imp. Acad., **3** (1927), 659; here also earthquakes within 10 years occurring in the same district is taken as one.

fluctuation in some geophysical or astronomical phenomena which may be in some physical connection with seismic activity.

Recently, the secular change in the length of day has aroused a revived attention among astronomers.(1) De Sitter(2) explains the secular acceleration and fluctuation in the longitudes of the moon, the sun, Venus and Mercury by some actual change in the change of the moment of inertia of the earth, and tidal friction. We reproduce here, in Fig. 2, his graph

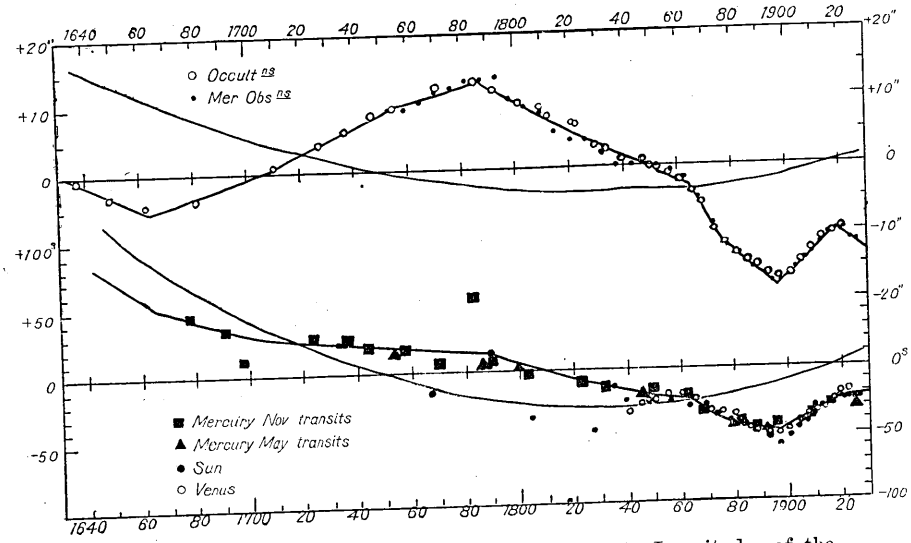


Fig. 2. Secular Accelerations and Fluctuation in the Longitudes of the Moon, the Sun, the Venus, and Mercury (De Sitter).

for the observed deviation of the moon's longitude from its purely gravitational value. The curve shows a conspicuous maximum near 1786 and a minimum at 1897. De Sitter regards the curve as consisting of a series of straight line of which the inclination against the time axis changes sometimes abruptly, corresponding to a sudden change in the length of day.

Comparing Fig. 2 with the graphs given in Fig. 1, we may notice that I*a* and V show some parallelism, while II*c* and III show a roughly inverted

(1) H. Spencer Jones, Monthly Not., **87** (1926), 4; E. W. Brown, Nature, **119** (1927), 200; J. K. Fotheringham, ibid, 318.

(2) W. de Sitter, Nature, **121** (1928), Supplement to No. 3038.

variation (parallel in absolute value of latitude) compared with Fig. 2.

According to De Sitter the maximum and minimum of his curve correspond respectively to some conspicuous increase and decrease in the moment of inertia of the earth. It seems for us more easy to conceive a change in the ellipticity than to assume after him a uniform expansion or shrinkage of an world-wide extent. If the change in ellipticity be chiefly effected by the external crust, while the core is unaffected, the greatest shearing stress will be endured by the intervening plastic "sima" layer near the middle latitude, i.e. at the node of the ellipsoidal deformation. Again, it is highly improbable that such a deformation will not find some expression in the seismic activity of the earth. It is then at least not inconceivable that the change in the ellipticity may in some way be connected with the change in the latitude of the zone thereby placed under the condition favourable for the occurrence of earthquakes. The fact that the curves of Fig. 1, taken as a whole, show a reversed (or similar, in absolute value) course of variation in latitude for the two hemisphere is in some degree favourable for this idea. It will, however, be useless to speculate on the possible mechanism which may give rise to such a kind of correlation between the changes in moment of inertia and the latitude of activity. Still, the relation here pointed out may deserve attention and stimulate a further investigation.

On the other hand, it has been frequently shown that there exists some singular correlation between the frequency of earthquakes and some climatic factor, though the physical meaning of the apparent correlation are for the most cases not clear and for that reason generally regarded with small weight. In our opinion, however, the occurence of earthquakes is physically connected with some meteorological factor, especially with the space and time distribution of atmospheric pressure, as was shown beyond doubt in many respects, especially by the seismologists in this country. On the other hands, all of the climatic factors must theoretically stand in some direct or indirect relation with the barometric pressure. It is well probable that the modes of interrelation are much complicated, so that two factors situated remote from each other in the complicated net-

work of causal connection may reveal a better correlation than some other two which are more closely related in the orders of causal sequence. In view of this consideration, it will not be out of place to compare the secular variation of latitude of earthquake with that of the rate of tree growth, already cited by a previous investigator(1) in an allied problem. Fig. 3*a* and *b* show the rates of growth of *Sequoia washingtoniana* and Arizona pine, the mean values for successive 50 year period being calculated from Douglass's data.(2) Comparing these curves with those in Fig. 1 it may be seen that Fig. 3*a* shows a remarkable parallelism with the curves

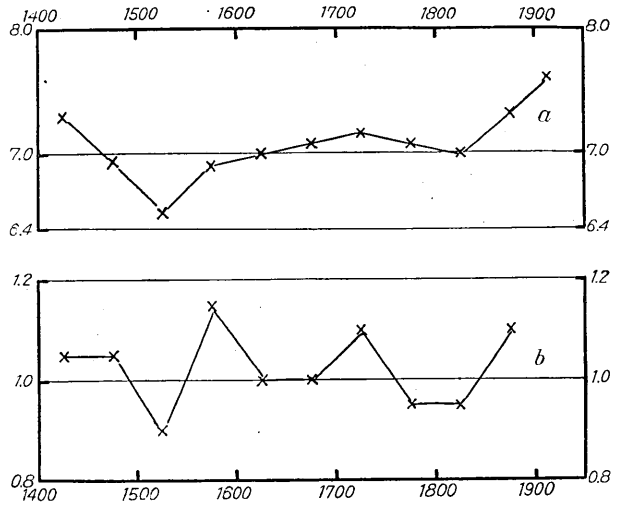


Fig. 3. Tree Growth (Douglass)
(*a*) *Sequoia washingtoniana.*
(*b*) Arizona pine.

for Chinese earthquake, Fig. 1, IV, while Fig. 3*b* has some features common with the variation in position of seismic activity in Japan, V*a* and *b*.

If we tentatively assume that the variation in the seismic activity here concerned is, on one hand, related with the deformation of the earth and, on the other hand, also connected with meteorological factors, we must necessarily admit a possibility of some relation, direct or indirect, between the two latter mentioned phenomena.

(1) H. H. Turner, M. N. R. A. S., **79** (1919), 531; **50** (1920), 617, 793.
(2) E. Huntington, "The Climatic Factor," p. 117, Fig. 20 and p. 327, Table G.

According to De Sitter a general shrinkage of the earth's radius by a few inches is sufficient for explaining the acute change in the length of day as is observed in 1918. In the case of an ellipsoidal deformation, the amount of the necessary change in radius will be somewhat larger, but of the same order of magnitude, as the equatorial zone is predominant. Taking for a rough estimation the case of hydrostatic equilibrium in a meridional canal filled with a liquid with the density of crustal rocks, say 3, a difference of 10 inches in the height of level will correspond to a pressure difference of 56 mm. Hg. As far as the authors are aware of, such a secular transfer of the atmospheric mass between the tropical and arctic zone has not yet been found, though it is well known that the mean or absolute range of variation of annual mean pressure is rather large especially for high latitudes. According to Hann's Handbuch der Meteorologie, the absolute range of January-mean for Paris in an epoch of 120 years amounts to 20.3 mm., which is at least of the same order with the value above calculated. The matter cannot, however, be so simple as here is assumed tentatively. It may suffice here to point out a possibility of actual connections among the phenomena compared statistically. We must wait perhap for a long time, until we can say something more definite about the problem here set forth.

Lastly, it may be pointed ont in passing that if there may exist some physical connection such as is above discussed between the deformation of the crust and some climatic factor, the much disputed problem of the climates in geological ages may be reviewed under a light somewhat different from as usual.