On the Correlation between the Long Period Fluctuation of Barometric Gradient and the Occurrence of Earthquakes in Kwatô District, Japan.

By

Win INOUYE.

關東に於ける氣壓勾配の長週期變化と地震發生との關係

所　員　井　上　宇　胤

宇都宮と布良及び銚子と甲府の毎日午前六時の氣壓の差を大正十五年一月から九月迄の九ケ月間中央氣象臺から發表して居る天氣圖の裏面の氣壓の價から求めそれ等を適當になだらかにしてから組合せて關東地方の氣壓勾配の長週期變化を求めました。

それに依ると圖一に見られる樣に東北一西南の方向の約九十日の變化と西北一東南の方向の約一年の變化とがあります。

そこで今村所員が震研彙報第三號に發表された此の當時の地震の中から五十五ケの有感地震を選び出して氣壓勾配の九十日の變化と比較しました。

氣壓勾配がその平均値より東北に偏しておるときに發生した地震を十の組とし西南に傾いて居るときに發生した分を一の組とし殆んど平均値に近いときに發生した分を？の組として圖二に各々の震央の上にそれ等の屬する組の符號を書き込みました。

此れに依ると同じ組の地震は互に集まつて地方的な集團をなす樣であります。

結局氣壓勾配の九十日の變化と共に地震が發生する地方が異なるかの樣になつて居ります。此の事實を一層確かめ且その意味を理解するために今村所員、中村左衛門太郎教授、松澤助教授、故大森教授の此の地方の地震に關する御研究及び矢部教授、東木氏の地質に關する御研究及び此の地方で行はれた重力測定、地磁氣測定の結果及び最近の陸地測量部の此の地方の構造線に關する御研究等と比較致しました。

尙又著者が陸地測量部に依つて確定された關東大地震後の此の地方の水平並びに垂直變位の結果を取り扱つたもの（圖三參照）、及び此の地方の數十ケの地震の震源の深さを決定したものをも參考致しました。

その上寺田所員が御親切にも上記の現象の一つの可能性ある模型的說明を御教示下さいましたが、遺憾ながら今日の狀態では此の問題並びにそれに類似の問題の眞の意味を了得する事が出來ない樣に思はれます。

然しとにかく氣壓勾配の長週期變化は地殼の傾斜運動を通して地震の發生と相關する樣に思はれますし、又其處には多少物質の粘性が要求されてるのではないかと思はれます。尙以上列擧した多くの他の成果と比較する事に依つてここに求めた有感地震の地理的集團と云ふものは可なり實在性のあるものと思はれます。

I. Introduction.

The question regarding the relation between the occurrence of earthquakes and certain quantities connected with the barometric pressures had already been investigated by many authorities.

Among them, late Prof. F. Omori[1] made a classical study of the relation between the earthquakes originating in different localities widely distributed in entire Japan and the barometric pressures at the corresponding stations.

Later Prof. T. Terada[2] made an investigation of the relation between the seismic frequencies and the barometric gradients in many parts of Japan for the first time, and then Dr. K. Hasegawa[3] studied the relations between the local earthquakes which took place near Gihu, central part of Japan, and the barometric gradients existing there at the epoch thirty minutes before the occurrence of the earthquake; still later, Prof. Saemontarô Nakamura[4] studied the same problem using the data of the local earthquakes which took place in Kwantô District, near Mt. Tukuba. They all agreed in concluding that the barometric gradients shortly before the occurence of earthquakes are generally perpendicular to the tectonic lines or weak lines already known by geological and seismological investigations in the localities in question.

Next, Prof. T. Terada[5] and Mr. Sadazumi Masuzawa determined the local distribution of the barometric gradients predominating at the time of occurence of the earthquakes for each of a number of districts in the main island of Japan, and came to attribute some definite type of stresses in the earth's crust to be the probable cause of these earthquakes.

Moreover, there are several other results of investigation of the allied problems obtained by Messrs. Daizô Nukiyama and Masayuki Mukai,[6] Prof. Saemontarô Nakamura,[7] Mr. T. Ishikawa[8] of the Central Meteorological Observatory, Tokyo, and Mr. K. Suda[9] of the Marine Meteorological Observatory, Kobe.

They have all studied the problem concerning certain quantities related to the barometric pressures at the time of the occurrence of earthquakes, but they, except Mr. T. Ishikawa, did not take into consideration any integral effect of these quantities prevailing before the time of earthquake for a certain duration.

Recently, Prof. M. Ishimoto[10] of our Institute expressed his view that the sensible after-shocks of the Tango earthquake of May 7, 1927, occurred mostly when the difference of the barometric pressures at Kyôto and Miyadu had been increasing for several days preceding the time of occurrence of the earthquake.

With the encouragement and advices by Prof. M. Ishimoto the present author studied the relation between the occurrence of the sensible earthquakes in Kwantô district and the long period variation of the barometric gradients prevailing there.

2. In the first place, the author calculated the difference of the barometric pressures between Utunomiya and Mera, Tyôsi and Kôhu and several other pairs of Stations, at 6 o'clock every morning, for the three months from July to September, 1926, using the data of the barometric pressures at the stations in question printed on the back page of the daily weather chart published by the Central Meteorological Observatory.

Smoothing these differences by using the formula

$$\overline{H}_n = \frac{H_{n-2} + 2H_{n-1} + 3H_n + 2H_{n+1} + H_{n+2}}{9}$$

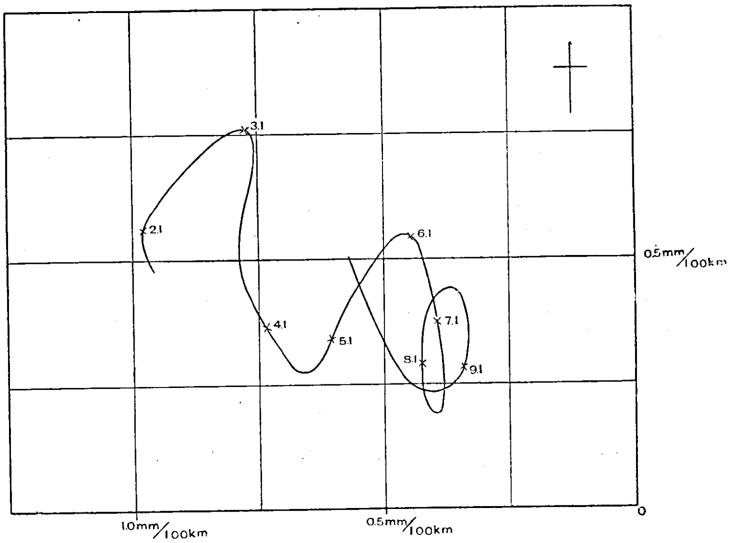
the author found that there exist several kinds of periodic variations i.e. with the periods of about 7 days, 15 days, 20–40 days and 90 days.

Using the usual method of eliminating the periodic variation with n day period in the case when such a periodic term exists in the observed phenomena i.e. by taking the mean values for successive overlapping intervals of n day, the author eliminated the short period fluctuation from the differences of the barometric pressures at Utunomiya and Mera as one group and at Tyôsi and Kôhu as another group, using the data of the barometric pressures during 9 months between January and September, 1926, by putting $n=5$ days, putting $n=15$ days and $n=27$ days I could eliminate the more or less longer period fluctuation, and could find that the long period variations amount to about 90 days and one year.

As the two lines connecting respectively the stations Tyôsi-Kôhu and Utunomiya-Mera are situated perpendicularly to each other in Kwantô district and the distance between the two stations of each pair are about 200 km., the barometric gradients could be determined by combining the two differences as shown graphically in fig. 1.

As seen from the figure, the appearance of the vector diagram of the barometric gradients looks like a Lissajou's figure, and is composed of the two variation one in NW-SE direction with a period of one year, and another in NE-SW direction with a period of $\frac{1}{4}$ year or 90 days.

Fig. 1. Long Period Fluctuation of the Barometric Gradient in Kwantô District between January and September, 1926.



The amplitudes of these variations, corrected for the decrease due to the process of smoothing, are 7.5 μ/km. or 1.5 mm. Hg per 200 km. for the longer period variation and 5 μ/km. or 1 mm. per 200 km. for the shorter one.

The above results are quite similar to that obtained by Prof. T. Terada in his paper above referred to. In the latter the barometric gradients in Kwantô district were determined by the monthly means of the barometric pressures at four stations lying at the four corners of a rectangle, namely Wajima, Niigata, Tyôsi and Nagaturo.

3. Next, the author compared the long period fluctuation of the barometric gradients thus obtained with the occurrence of the sensible earthquakes.

The data of earthquakes are taken as far as possible from the list reported by Prof. A. Imamura[11] of the earthquakes which occurred during the nine months between January and September, 1926, in Kwantô district. I could use 55 sensible earthquakes for the purpose.

As for the barometric gradient, only its variation with the period of 90 days was taken into consideration. The barometric gradients at the beginning of January could not be obtained on account of the method of procedure here used and the lack of the data, but the value was assumed according to the result of Prof. T. Terada above cited.

These earthquakes will be classified into three classes according to the direction of the barometric gradient vector at the time of their respective occurrences. When the barometric gradient vector at the time of occurrence of a certain earthquake deviates to NE or SW from its mean position, we will indicate the epicentre of the earthquake with the mark + or − respectively on the map as shown in fig. 2. The epicentres indicated with a mark ? in the map are those of the earthquakes, at the time of occurrence of which the vector scarcely deviated from its mean position.

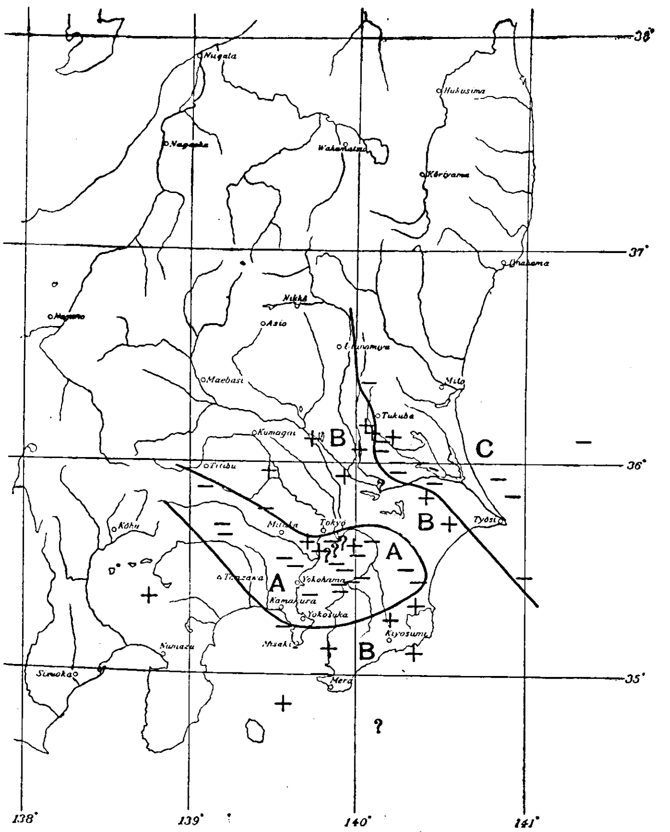


Fig. 2.

The number of earthquakes which fall into the groups with the mark +, −, and ? are 18, 32 and 5 respectively. Thus it appears that the earthquake occurs rather frequently when the vector of the barometric gradient is deviated to SW.

The geographical distribution of the epicentres of the earthquake seems to be more or less systematic, the epicentres specified with the same mark swarming together into rather definite local groups.

The geotectonic significances of the boundaries of these groups may be mentioned later in more or less detail.

By the way, Prof. Saemontarô Nakamura[12] compared the mean anomaly of the sea level determined from the records of the tide-gauges at Tyôsi, Mera and Yokosuka mareographical stations, during two days before the occurrence of the earthquakes, on the day when they occured and duringtwo day s after the occurrence of them, with the time of occurrence of after-shocks of the great Kwantô earthquake of September 1, 1923, and he obtained the result that the positions of epicentres of the earthquakes, which occurred when the mean anomalies of the sea level at a given station had been positive and negative respectively, were distributed in groups. Moreover, when we take into consideration the assumed tilting of the earth's crust in the district, which may be obtained by combining the mean anomalies at each station supposing that the mean anomalies of the sea level are due to the movements of the earth's crust and not to the fluctuation of the sea level caused by any meteorological or astronomical causes, we found that the positions of epicentres of earthquakes which occurred at the same phase of the tilting movement of the earth's crust in the direction towards NE and SW alternately, are crowded together within a definite area.

In the main feature, the latter geographical groups of earthquakes as regards the assumed tilting of the earth's crust are quite similar to that obtained by the present author. But he finds slight discrepancies among these groups, which may be mainly attributed to the difference of the accuracies in determining the epicentres of these earthquakes. Moreover, as to the mode of tilting of the earth's crust prevailing when the earthquakes of any one group take place, the author is quite in accordance with Prof. Saemontarô Nakamura, if the earth's crust could be considered to yields to the difference of the barometric pressures.

Now, according to the results obtained by the author, the two Kinugawa seismic zones must become active alternately and complete one cycle of activity within 3 months, because they cover the domains B and C in fig. 2. and as the Tama seismic zone enters into the domain A, it must be in action during the early part of each cycle and be dormant during the later half.

Prof. A. Imamura mentioned in his report (in Japanese), above cited, as follows, which I will here quote translating into English.

"We have two seismic zones along the drainage basin of the River Kinu, and the activity has migrated from one to another of these zones within these three months, and this cycle of minor activity became more and more clear in the succeeding three months."

He also says in his English abstract of his report, "The most conspicuous feature may be a completion of cycle or epoch of minor activity in the Tama seismic zone. It became rather active in January about the middle point of the zone: the activity migrated a little eastwards in February, but was less active in March. Similar movement was repeated during the subsequent three months, but in July the activity was revived with augmented energy in the western part and at last it calminated on Aug. 3 about the middle point of the zone causing slight damages in Yokohama and Tokyo. Afterwards, more or less after-shocks were experienced for a few days, but finally the whole zone became quiet."

4. The author determined the amount of dilatation and contraction of the distances between the neighbouring stations, reduced to per 1 km., using the data of the horizontal displacements in the area disturbed by the great Kwantô earthquake, which had been revealed by the triangulation carried out by the Land Survey Department.(13)

The values are written down in the annexed fig. 3. on the middle points of the lines connecting the neighbouring two stations with positive and negative sign according to elongation and contraction respectively. As seen from the figure, even if there are some regions where positive and negative signs occur mixed together probably on account of some local shearings, the same signs, are found as a whole, grouped together in definite areas. When these features are compared with the mode of distribution of the vertical displacements in Kwantô district detected by the leveling work of the Land Survey Department(14) carried out after the great catastrophe, it seems that in the elongated portion, the surface of the earth's crust was stretched in its horizontal extention smoothing its furrows more or less in way of its subsidence, and in the contracted portion the earth's crust shrinked horizontaly in the process of its elevation.

The boundary of the portion with horizontal dilatation are quite similar to that of the seismic domain A in fig. 2. along the drainage basin of the River Tama, which I obtained as the result of my investigation of the relation between the barometric gradients and the time of the occurrence of the earthquakes. It seems that they are physically connected with each other.

5. To determine the geological meaning of these boundaries of regions with different feature of seismic activity, the author studied some papers dealing with the geology of the district.

According to the opinion of Prof. H. Yabe and Mr. R. Aoki(15) the boundary between the portions A and B in fig. 2. along the southern part of the

Bôsô peninsula and Sagami seems to have a geological meaning as follows.

The main part of the Bôsô and Miura peninsulas and Ôiso block, which had been forming the horst extending in E-W direction, were disturbed by the Post-Narita disturbances, the latest one in the district, opening a channel in the intermediate portion.

Next, according to Mr. R. Tôki's[16] chronological researchs on the fluctuation of the level of the eroded surfaces in Kwantô district, the drainage basin of the River Kinu, along which is extended the boundary between the portion B and C, had been repeating the tilting motions sometimes eastwards and sometimes westwards in the geological era, and it may thus be assumed to be in activity even now.

6. Next, the author examined the results of the gravity observation and the magnetic survey in the district.

According to the result obtained by Prof. M. Matuyama[17] the anomalies of gravity in the region A seems to be smaller than in the neighbouring regions though the complete corrections for the neighbouring topography and isostasy are not yet performed. W. Heiskanen,[18] applying isostatic correction according to Hayford's method, found that the gravity anomalies of this portion are negative.

According to the results of the magnetic survey, reduced to the epoch 1895.0 which was carried out by many able physicists of our country under the guidance of Prof. A. Tanakadate,[19] the rocks consisting the lithosphere of the portion A seems to be less magnetic than that consisting the neighbouring portions, because an apparent valley line of the magnetic disturbing force, though its existence is not quite certain, lies just in this district. Recently, the Hydrographic Department, Imperial Japanese Navy[20] carried out the magnetic survey several times all over Japan, but the results cannot be here utilized, as the number of stations in this district are too scarce for this purpose.

7. Next, the author calculated the focal depths for 33 among the 55 earthquakes in question, as they could be determined more or less distinctly using Omori's formula for the focal distance. Moreover, the focal depths of ten earthquakes which occured during 1927, were determined by the ratios of duration of the preliminary tremors at more than 4 stations taken among Tokyo, Kamakura, Misaki, Kiyosumi, Titibu and some other meteorological stations. For

the details regarding these earthquakes Prof. K. Suehiro's[21] paper may be referred to.

The values of the focal depths thus obtained range from 15 km. to 85 km., and most of them are within 60 km. . The author found that the focal depth of the earthquake of domain A might not much exceed 60 km.

Moreover, the author could verify this result by the result of an allied investigation of one of my colleague Mr. R. Takahashi. The significance of this result shall be mentioned later.

8. Next, studying the paper by late Prof. F. Omori[22] "Macro-seismic Measurement in Tokyo," the author found that the domain F of the "insensible earthquake" in Pl. II. "Map showing the distribution of the origin of the earthquakes in Central Japan, which were not felt in Tokyo, Sept. 1887 to July 1889" is quite similar in its form to our domain A, except the western portion which in the case of Prof. F. Omori is extended to as far as Matumoto, Nagano and Niigata but in the author's case the boundary is ambiguous.

De Montessus de Ballore mentioned on P. 339 of his book "La Science Seismologique" regarding the domaine F as follows.

"Inversement, il se forme aussi des zones portant ombre séimique, ou faisant pont, comme on dit, et dont il a déjà été question; elles trouvent leur raison d'être de la même manière dans l'agencement relatif, près de la surface terrestre, des couches anciennes à grands modules d'élasticité et de rigidité par rapport aux couches plus récentes au sein desquelles le mouvement séismique se propage moins rapidement et, partant, moins énergiquement. Kusakabe tire argument, en faveur de ces intéressantes considérations, de la distribution des origines des tremblements de terre qui, de Septembre 1887 à Juillet 1889, n'ont pas été ressentis à Tokyo, en dépit de la proximité de leurs origines et même de l'intensité parfois assez grande de ces secousses. La curieuse disposition de la carte de ces origines, établie par Omori, peut certainement s'expliquer, dans une certaine mesure, au moyen de ces conséquences des recherches de Kusakabe."

It is a question whether this results may be attributed to the difference of the rocks composing the lithosphere of different parts of the district in the sense above quoted or to the hypothetical secular change of the activity of the insensible earthquakes. At the time when Prof. F. Ômori investigated the insensible earthquakes, they occurred only in some separated domains; which may be attributed to the secular change in the activity of this kind of earthquake.

Moreover, examining the space distribution of the direction of major axis of the disturbed area in the cases of 47 earthquakes given in Table II. of the paper by Prof. F. Omori, above quoted the author found that the epicentres of the earthquakes which have more or less similar, direction of the major axis are grouped in some definite localities quite similar to those which the author here obtained, namely the domains where the major axis take NE-SW direction are quite in accordance with the domains A and C, and where they take from E-W to NW-SE direction the domain are quite similar to the domain B. The authour thinks that the direction of the major axis of the area of disturbance, though they cannot be determined very accurate, is connected in some ways with the tectonie lines or weak lines in the district.

Further, very recently, Messrs. Mutô and Atumi, the experts of the Land Survey Department, determined the trends of the tectonic lines in Kwantô district very accurately, utilizing the data of the precise leveling performed several times in the district. According to their result, the predominating directions of the tectonic lines in the portion A and B are quite different; namely in the portion A they take N-S and E-W directions, and in the portion B they take NE-SW and NW-SE directions.

9. Recently, Prof. T. Matuzawa, Messrs. K. Hasegawa and S. Haeno[23] investigated the forerunners of earthquake-motions of certain earthquakes, and it seems to the author that the region bordered by chain lines in fig. 7 of their work, where those earthquakes occurred in which the development of each of the three phases due, according to them, to the refraction of seismic waves at the boundary between the surface layer 7 km thick and substratum, is remarkably observed at Tokyo, may be quite in accordance with the eastern portion of the domain B.

Moreover, as quoted by the above authors late Prof. F. Ômori confirmed that the earthquakes accompanied with detonative sounds had occurred nearly in the same region as those considered here.

10. Next, as to the correlation of the mutual activity of seismic zones or domains it was late Prof. F. Ômori[24] who has made investigation for the first time. Afterward, Prof. A. Imamura[25] studied the alternation of activity in the two seismic zones with the minor activity in Kyûsyû.

According to Mr. R. Hirano's[26] investigation the after-shocks of the great

Kwantô earthquake have become ative alternately in two regions with a period of 19 days, and Mr. K. Suda says that these earthquakes could be separated in two domains namely Bôsô and Sakawa-Sagami domain, exhibiting an alternate activity.

Moreover, K. Siratori[27] have made a study on the same problem. Mr. K. Wadati[28] of the Central Meteorological Observatory studied the fluctuation of the activity of the outer zones in recent years. Recently, Prof. T. Terada,[29] Mr. N. Miyabe[30] and Mr. T. Takayama[31] also investigated the similar problems.

Nevertheless, to the author's great regret, the true meaning of these phenomena seems to be yet unknown.

II. Discussion.

Let us consider the mechanism by which the variation of the barometric gradients may bring about the occurrence of the earthquake.

The earthquakes occur in the region on the one side of any boundary at the epoch when the barometric gradients deviate to a certain direction from the mean position, and on the other side they take place when the gradients deviate to the opposite direction. Thus, we must consider the mechanism as such that the earthquakes in any one seismic domain occur at the epoch when the barometric gradients deviate to a certain direction from the mean position in the course of their fluctuation with a period of 90 days.

The author is at present not yet in a position to express anything definite on this point, but may be allowed to mention here one of the possible mechanisms which was suggested to him by Prof. T. Terada, in the following.

Suppose two adjacent blocks of the crust be in somewhat loose contact with each other at an inclined faut plane forming the boundary between the blocks. If the atmospheric pressure be higher on the block on the upper side of the inclined boundary plane than on the other, the contact between the two blocks will be tightened, whereas if the pressure distribution be in opposite sense there will ensue a tendency to loosen the junction between them and thence to facilitate a dislocation along the weak plane of fault.

12. At any rate, according to the author's opinion, the variation of the barometric gradients cannot be the primary cause of earthquakes though it may act under some favourable conditions as a secondary cause or serve as a trigger action of earthquakes.

According to the author's result that the long period variation of the barometric gradients has some effects upon the occurrence of earthquakes, the author is led to assume the existence of some plastic material in the mechanism of the trigger action in question.

The assumption of such a plastic material may be found in several instances. For example, the elegant work of A. Wegener on the theory of the continental drift, and the theory of isostasy are powerful enough to make many eminent geophysicists believe the existence of a plastic material between the solid earth's crust and the dense core. As to the remarkable displacements in vertical direction which took place in the bottom of the Sagami Bay, which has been revealed by the sounding carried out by the Hydrographic Department, Imperial Japanese Navy, Prof. T. Terada[32] of our institute attributed it to the high plasticity of the substance composing the deep sea bottom in that region; moreover, he expressed his opinion, recently, that the material beneath the lithosphere of our country is more or less rich in fluidity, which he infers from the results of the precise leveling carried out by the Land Survey Department in the disturbed area of the Tango earthquake of March 7, 1927. Next, the plastic material may be assumed in the portion of the solid part of the earth's crust suffering enormous stresses.

Moreover, many folded structures, especially of the famous overthrust in the Alps, exhibit a fairly plastic nature of the material. It is needless to cite the plasticity of the magmas and lavas of volcanoes.

13. A further consideration about the geological structure of the district may here be added. According to the results of the gravity observation it seems that the earth's crust in the seismic domain A may consist of a more light material than the neighbouring regions; moreover, the rocks consisting the lithosphere of that portion may be less magnetic than the neighbouring rocks as seen from the results of the magnetic survey.

The density of the more or less acidic rock or some kind of granitic rock may be less than the ordinary rock consisting the sial part of the earth's crust; moreover, it is quite probable that the former may also be less magnetic than the latter.

The author is thus led to suppose that the portion A is composed of some such granitic rock, so that the gravity anomaly and the intensity of the terrestrial magnetism are all less than the neighbouring portion.

By the way, the fact that the focal depths of the earthquakes which took place in the portion A did not exceed 60 km., and forms a striking contrast to the neighbouring portions where the earthquakes occur more or less frequently with the focal depths amounting to 100 km., suggest that the thickness of the lithosphere of the portion A is smaller than that of others, moreover, it suggests that in these portions fairly good isostatic compensation exists. As there seems to exist the isostatic compensation in those two portions having the same height above sea level, the one in which the thickness of the sial part is rather small will be composed of more light material, and the other in which the thickness of the sial part is rather great must be composed of more dense substance.

14. Probably, the boundaries of the seismic domains determined by the above investigation are not of a permanent nature, because it is a question whether the apparent boundar may differ to some extent from time to time or not, owing to a secular variation of the effects of the primary and the secondary causes of earthquakes and of some mechanism connecting the domains with one another.

As seen from the author's investigation, at the epoch here in consideration, there were several seismic domains of the sensible earthquakes in Kwantô district, and some of them became active simultaneously and some of them alternately, and the cycle of their minor activity was completed within three months quite in accordance with the periodic variation of the barometric gradients with the period of about three months existing there simultaneously.

Further, the author hopes that the reader will keep in mind that this relation between the two phenonena now in question may be disturbed by some more effective agents under some unknown conditions.

It seems to the author that there are some phenomena of kindred nature; for instance, Mr. T. Takayama recently found that some seismic domains became active simultaneouly in some epoch and alternately in the other epoch. Again, it is a well known fact that some volcanoes exhibit several phases in their activities. In meteorology also may be found many examples of such phenomena. Moreover, it is a question whether the apparent parallelism between the variations of the seismic activity and the barometric gradients may be caused by some one and the same fundamental cause or not.

Nevertheless, it is quite significant that the seismic domains revealed by the present investigation are connected with the phenomena such as gravity, terrestrial magnetism, again with the orogenic events in geological era and even in the present time, with the mean anomaly of the sea level, focal depths, forerunner, earthquake sound, direction of the major axis of a disturbed area, tectonic lines and the space distribution of the epicentre of the insensible earthquakes. After all, the author is of opinion that the variation of the barometric gradient shows some apparent correlation with the occurence of earthquakes as the variation is related with the tilting motion of the earth's crust.

15. In conclusion, the author expresses his cordial thanks to Professors Torahiko Terada, Sakuhei Fujiwhara, Misio Isimoto, Messrs. Chuji Tsuboi, Ryûtaro Takahasi and Chuji Yasuda in our Institute for their kind advices and encouragements, and to Mr. Minoru Ôtuka for his kind assistance in preparing the figures in the present paper.

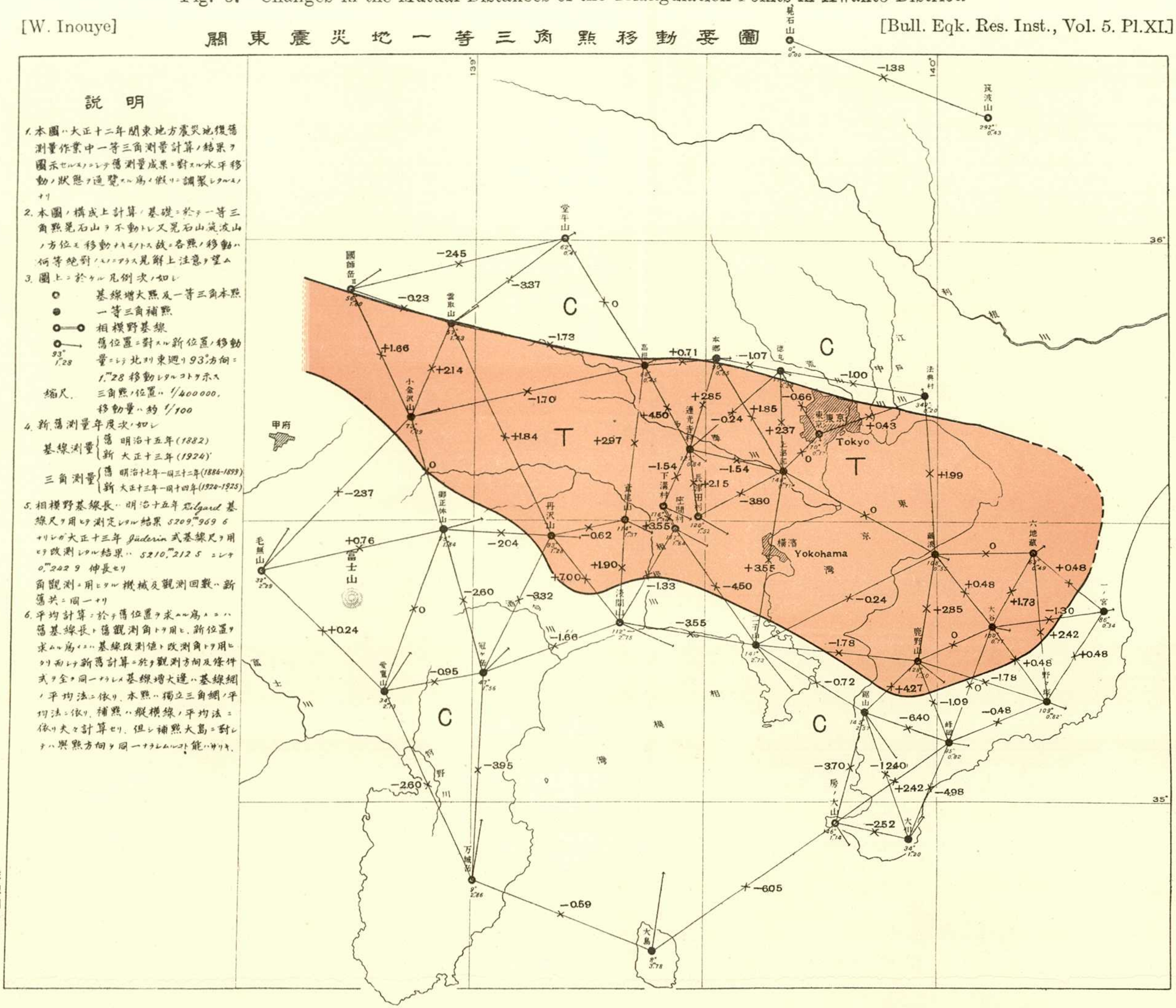
References.

(1) F. Omori, Pub. E. I. C., in Foreign Languages No. 8.
(2) T. Terada, Journ. Met. Soc., 28 (1909), 1.
(3) K. Hasegawa, Proc. Tokyo Math.-Phys. Soc., 1913. p. 181.
(4) Saemontarô Nakamura, Proc. Tokyo Math.-Phys. Soc., 1915. p. 69.
(5) T. Terada, Proc. Physico Math. Soc. Japan, 3rd Ser., Vol. 1. No. 10-11.
(6) D. Nukiyama & M. Mukai, Jap. Journ. Astro. Geophys., Vol. 1. No. 2. 1922.
(7) Saemontarô Nakamura, Japanese Journ. Astro. Geophys., Vol. III. No. 2, 1925.
(8) T. Ishikawa, Journ. Meteoro. Soc. (11), 3 (1925) p. 255.
(9) K. Suda, Mem. Imp. Mar. Obs., 1, No. 4. (1924).
(10) M. Ishimoto, Bull. Earthq. Research Inst., Vol. 4.
(11) A. Imamura, Bull. Earthq. Research Inst., Vol. 3.
(12) Saemontarô Nakamura, Jap. Journ. Astro. Geophys., Vol. 4. No. 3, 1927.
(13) Bull. Earthq. Reseach Inst., Vol. 1.
(14) Sinsai-yobô-tyôsakai-hôkoku, 100, B.
(15) H. Yabe & R. Annual Report Saito Gratitude Foundation, No. 1, May, 1926.
(16) R. Tôki, Tirigaku-hyôron, Vol. 4, No. 2, Feb., 1928.
(17) M. Matsuyama, Pub. Bureau Centr. Seism, Intern. Sériè A. Traveau Scient. 2 (1925) pp. 1-24.
(18) W. Heiskanen, Zeitschr. f. Geophys., III. (1927) Heft 5.
(19) A. Tanakadate, Journ. College Seience, Imperial Univ. Tokyo., Vol. 14.
(20) Bull. Hydrographic Depart., Imperal Japanes Navy, Vol. 5.

(21) K. Suehiro, Pro. Imp. Acad., Feb., 1928.
(22) F. Omori, Pub. E. I. C., No. 11.
(23) K. Matuzawa, K. Hasegawa & S. Haeno, Bull. Ekque Reseach Inst., Vol. 4.
(24) F. Omori, Bull. Imp. E. I. C., Vol. 1. No. 1.
(25) A. Imamura, Sinsai-yobô-tyôsakai-hôkoku, 92. (1920).
(26) R. Hirano, Journ. Meteoro. Soc., Ser. 2. Vol. 2. No. 3.
(27) K. Siratori, Jap. Journrn. Astro. Geophys., Vol. 2 p. 182.
(28) K. Wadati, Journ. Meteoro. Soc., Ser. 2. Vol. 4. No. 7.
(29) T. Terada & N. Miyabe. Proc. Imp. Acad., 3 (1927), No. 5.
(30) N. Miyabe, Poc. Imp. Acad., 3 (1927), No. 10.
(31) T. Takayama, Bull. Earthq. Reseach Inst., Vol. 4.
(32) T. Terada, Pro. Imp. Acad., Feb, 1928.

Fig. 3. Changes in the Mutual Distances of the Triangulation Points in Kwantô District.

[W. Inouye] [Bull. Eqk. Res. Inst., Vol. 5. Pl. XI.]



+elongation
−contraction (unit in cm./km.)

T and C represent the horizontally elongated and contracted regions respectively.