An Interpretation of the Results of the Repeated Precise Levellings in the Tango District after the Tango Earthquake in 1927.[1]

By **Chûji TSUBOI.**

Earthquake Research Institute.

昭和二年丹後地震後の水準測量成果の一解釋

坪　井　忠　二

昭和二年三月七日丹後地方を襲つた大地震に就ては、各方面に亘つて盛に研究が行はれた爲に地震に關する我々の知識が餘程進歩した樣に見える。其の中で最も著しい業績の一つは陸地測量部の手に依つて行はれた同地方の三角測量と水準測量との改測である。丹後地方には古い水準路線が一本通つて居るが此の他に地震後同地方には新に路線が幾本も設けられて之等の路線に沿つて水準測量が繰返して行はれることになつた。夫等の水準路線は第二圖に點線で示した通りである。水準測量は地震後今日迄に既に三回も繰返されて其の結果は其の都度研究所彙報に發表されて居る。夫等の結果から我々は丹後地方の地殼が地震後次第に變動して行く有樣を知る事が出來るのである。之等の測量の結果は非常に貴重な材料であつて出來るだけ色々な立場から解釋して見る事が必要であらう。既に寺田、宮部兩氏は地震後の三角測量から求めた地殼の水平運動と水準測量から求めた垂直運動との間に密接な關係がある事に注目して此の地方の地震後の運動はアイソスタシーの理論の要求する所と一致して居ると述べられて居る。自分が之等の問題に興味を抱いて居つた時偶々東北帝國大學の田山學士の「丹後但馬地震地域の地體構造と最近地史に就て」(齋藤報恩會學術研究報告第六號)が發行された。同氏の論文中の第一圖には但馬丹後地方の地塊が非常に細く圖示されてある。此の圖を見て居て早速氣が付いた事は此の樣な構造と地震後の地殼の變動との間に何か關係がありはしまいかと云ふ事であつた。それで早速調査を始める事にしたのであるが此の點に就いて田山氏の論文から暗示を得た事に對して謝意を表して置き度い。

それで次の樣な方法に依つて調査を行ふ事にした。第二圖に示した樣に水準路線の中で比較的急に屈曲して居る點に A B C 等の名を付けて夫等の相隣る二つ

---

(1) Preliminary report appeared in Proc. Imp. Acad., 4 (1928), 529.

を直線で結び其の間にある各水準點を此の直線の上に直角に投影した。此の投影を水平軸に採り各水準點の高さの變りを垂直軸に採つて地殼の變動を表して見ると第三圖の樣になる。圖中 ● は第一回水準測量と第二回との間の變動量を ○ は第二回と第三回との間の變動量を表したものである。此の圖で著しく氣が付く事は各水準點の變動を表す點が多くの直線分の上に乘つて居る事と夫等の直線分の交點が ● と ○ との二系列に就いても略同一の横軸上にある事とである。之等の事實を說明する爲に此の地方が所謂地塊から成立つて居て夫等が宛も水に浮んで居る木片の集りの樣に個々別々の運動をして居るとも考へられるであらう。特に第三圖で見られる樣に時に依つて傾動の方向を變じて居る地塊もある事は此の考を裏書する樣である。此の樣にして水準測量の結果の方から定めた地塊は第四圖に示した通りである。又一方地質學的方面の材料から定めた新しい斷層や地質學上の弱線は第五圖に示した通りである。第四圖の地塊の境を之等の斷層の位置と比較して見ると二つのものが極めてよく一致して居る事が認められる。卽地質學上の新らしい斷層は今なほ活動して居て夫が水準測量の結果に現れたと考へるのが至當であらう。數年間の觀測で測り得る程の短い間の地殼運動にも地質學上の構造が之程の意味を持つて居ると云ふ事は誠に注目す可き事と云はなければならない。之等の地塊運動と丹後大地震や其の餘震との間の關係に就いて何かはつきりした事を云ふ事は今の所では出來ない。唯注目すべき事實として第三圖 b の樣に二つの地塊が始めは共通な傾動をなしてから後に別々の運動を始めた時に其の二つの地塊の境で發生したと考へられる樣な餘震が觀測されなかつた事を擧げて置く。若し地下に何か活動力の源となる樣なものを假定すれば其の影響を受けて一方では或る地方の地塊運動が促進され又他方では其の地方に地震が起こされると考へる事も出來るかも知れない。此の樣に考へると地塊運動と地震と云ふものは互に原因結果の關係で連なつて居るものではなくて共通の原因の二つの違つた現れと解釋す可きであるのかも知れない。

昭和三年十月

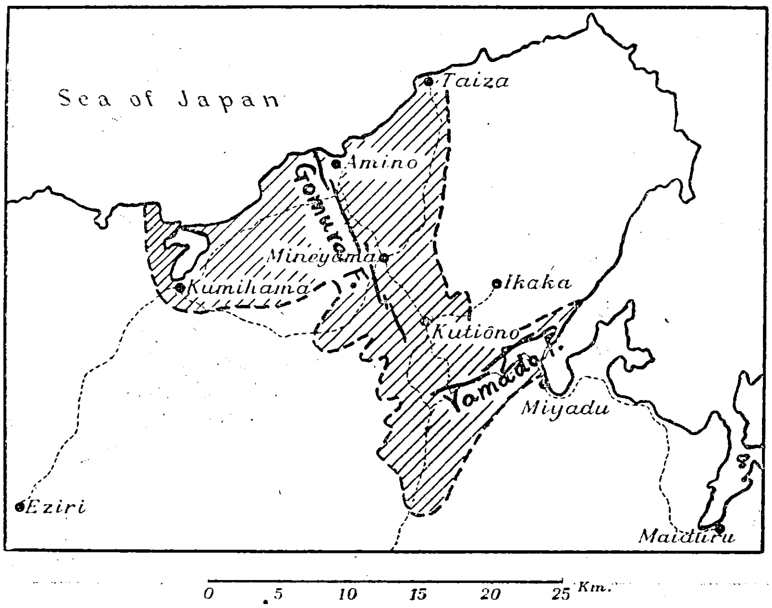
---

1. In the country of Japan, from which a world-shaking earthquake originates not rarely, the scope of seismology naturally goes further beyond the study of the propagation of purely elastic seismic waves and is extended to the investigation of those geophysical phenomena that are characteristic to the localities of the earthquake origin. Thorough studies of these phenomena are of prime importance for the earthquake research, as by means of those studies some informations are likely to be obtained concerning the cause and the mechanism of the occurrence of an earthquake. A change in the topographic features often observed in the case of a severe earthquake

in the neighbourhood of its origin, such as the formation of a remarkable fault, the warping of the ground, etc., is one of the most remarkable of these phenomena. Such topographic changes are sometimes too remarkable to be overlooked in passing observations, but they are often only to be detected by a series of delicate instrumental measurements. Thus, for instance, they are revealed by the comparison of the results of triangulations or precise levellings carried out before and after an earthquake over the disturbed area. During the past 40 years, 9 earthquakes have been reported(1) in this country with which some topographic changes were revealed to have accompanied, and it was also the case with the Tango great earthquake of 1927.

2. The Tango earthquake of which 2908 persons fell victims took place on March 7th, 1927, with its epicentral position $\varphi = 135° 1' E$, $\lambda = 35° 39' N$ as determined by Prof. A. Imamura.(2) In this earthquake,

Fig. 1. Shades....Meizoseismal Area.



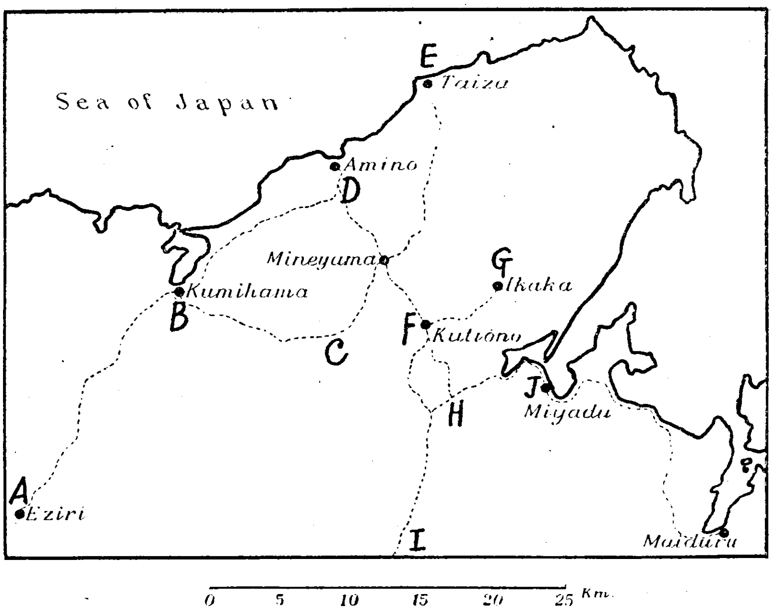
(1) A. Imamura, Proc. Imp. Acad., 4 (1928), 56.
(2) A. Imamura, Bull. Earthq. Res. Inst., 4 (1928), 179.

two remarkable faults were formed in accordance with the old dislocation lines, namely the Gômura fault and the Yamada fault which run nearly perpendicular to each other as shown in Fig. 1.(1)

All the geologists who visited the disturbed area and tried to trace back the history of the geological development of this district agree in saying that this earthquake is nothing but an episode in the course of geological development of this district.

3. Immediately after this earthquake, the Japanese Land Survey Department undertook the revision of triangulations and precise levellings over the disturbed area. One levelling route runs across the meizoseismal area along which precise levellings were once carried out 40 years before the earthquake. In addition to this, a number of bench marks were newly installed after the earthquake along the main roads in this district so that a net of the levelling routes thus laid out covers closely the disturbed area. These levelling routes are shown by dotted lines in Fig. 2.

Fig. 2.



(1) Taken from N. Yamasaki and F. Tada, Proc. Imp. Acad., 3 (1927), 223.

The postseismic levellings were repeatedly carried out along these routes in view of getting, if possible, some informations regarding the mode in which the ground in this district settles after being greatly disturbed by the catastrophe. The first of the postseismic levellings was carried out from April 12 to June 16, 1927, the second from June 1 to July 31, 1927, and the third from March 3 to April 20, 1928. The results of these levellings were already published in the Bulletin of this Institute.[1] These results are extremely interesting and have already been subjected to much discussions.[2]

In the present paper will be given the results of a comparative study made upon the results of the three series of the postseismic precise levellings, by which a very peculiar mode in the settling movements of the crust in this region was found.

4. The vertical displacements of the bench marks in the Tango district in the interval between two successive levellings are given in the following tables. The data in the tables were taken from the series of reports by the Land Survey Department and were rearranged into a form to be conveniently referred to. The geographical positions of the bench marks may be identified by the reference to the map in Fig. 2.

TABLE I.

I....Height in the first levelling.
II....Height in the second levelling.
III....Height in the third levelling.

Bench Mark	II−I	III−II
		mm
1363		−17.4
1364	mm	−18.0
1365	+8.5	−17.3
1366	+6.2	−19.1
1367	+5.0	−19.3
1368	+4.9	−15.8

(1) The Land Survey Department, Bull. Earthq. Res. Inst., 3 (1927), 167; 4 (1928), 225; 5 (1928), 165.
(2) T. Terada and N. Miyabe, Proc. Imp. Acad., 4 (1928), 211.

1369	+3.5	−16.1
1370	+2.3	−14.7
1371	+0.3	−15.0
1372	+0.2	−14.2
1373	−1.1	−14.6
1374	−0.5	−15.6
1375	−2.0	−13.0
1376	−1.0	−13.0
1241 (J Miyadu)	−3.5	−11.0
1240	−3.2	− 8.7
1239	−1.2	− 8.7
1238	−2.2	−10.2
1237	−3.6	−15.8
1236	−2.8	−11.1
1235 (H)	−0.1	+ 1.2
1234	−2.7	+ 2.8
1233	−1.4	− 1.3
1232 (F Kutiôno)	0.0	0.0
1231	−5.8	− 2.2
1230	−5.2	− 6.3
1229 (Mineyama)	−3.1	− 2.4
1228	+2.5	+ 7.6
1227	−2.5	+ 5.0
1226 (C)	−8.0	+ 4.6
1225	−9.0	+ 2.8
1224	−7.0	+ 1.0
1223	−2.5	+ 0.5
1222	−5.6	+ 2.5
1221	−7.8	+ 4.3
1220	−6.0	− 4.0
1219	−5.1	− 2.2
1218 (B Kumihama)	−8.5	+ 0.2
1217	−7.1	+ 1.9
1216	−3.6	+ 2.6
1215	−3.5	+ 2.4
1214	−1.1	− 0.4
1213	+0.4	− 7.3
1212	—	−23.5
1211	−3.0	−22.2
1210	−2.4	−16.9
1209	−1.2	−17.7
1208	−1.8	−20.9
1207	−0.2	−22.7
1206 (A Eziri)	−0.1	−22.4

TABLE II.

Bench Mark	II—I	III—II
1256	+3.0	−38.8
10446	+4.7	−38.0
10447	+5.7	−39.3
10448	+9.2	−41.0
10449	+9.2	−37.7
10450	+10.7	−33.7
10451	+5.8	−32.7
10452	+4.4	−33.5
10453	+6.1	−35.8
10454	−2.1	−31.0
10455	−5.2	−25.3
10456	−4.0	−19.7
10457 (I)	+0.8	−17.8
10458	−0.8	−18.1
10459	+0.2	−14.0
10460	−2.4	−11.6
10461	−2.6	−23.8
10462	−3.4	+ 6.8
10463	−1.1	− 5.0
10464	+2.5	+ 6.4
1232 (F Kutiôno)	0.0	0.0
10465	−0.8	− 4.9
10466	−1.4	− 3.3
10467	−2.4	− 4.4
10468 (G Ikaka)	−1.6	− 1.4

TABLE III.

Bench Mark	II - I	III−II
1218 (B Kumihama)	−5.4	+0.2
10489	−6.8	+0.9
10488	−6.8	−0.1
10487	−3.5	−1.6
10486	−2.9	−0.3
10485	−2.2	−1.5
10484	−1.3	−2.6
10483	−1.3	+4.1
10482	+2.7	+6.6
10479 (D Amino)	+5.1	+12.4

TABLE IV.

Bench Mark	II—I	III—II
10481	+3.9	
10480	−0.5	
10479 (D Amino)	+5.1	+12.4
10478	+3.7	+10.0
10477	−2.2	+ 4.7
1229 (Mineyama)	−3.1	− 2.4
10469	−2.7	− 2.5
10470	−2.0	− 3.0
10471	−0.5	− 4.7
10472	+0.1	− 0.1
10473	+2.1	− 1.9
10474	+2.0	− 2.5
10475	+3.8	− 2.8
10476 (E Taiza)	+3.2	− 1.4

5. These results were subjected to an examination in the following manner. Every turning points of the levelling routes with a sharp bent was marked by A. B. C. etc., as is shown in Fig. 2, every adjacent two of which were connected by a segment of straight line. The position of every bench mark between the two points is normally projected upon the segment which connect the two. Taking these projections along the horizontal axis, the vertical displacement of a bench mark is represented by a point with its height from its foot taken proportional to $\triangle h$. A few examples of the diagrams thus obtained are shown in Fig. 3, in which the mark ● corresponds to the displacement of a bench mark during the interval between the first and second levellings while ○ to that between the second and the third.

In making these diagrams, the Kutiôno bench mark (No. 1232) was assumed as fixed in height throughout the three levellings to which the vertical displacements of all the other bench marks were referred. No loss in generality is, of course, introduced by this assumption.

6. Two remarkable features will be recognised in the manner of distribution of the points in the diagrams; the one is that the points lie on a number of segments of straight lines, and the other is that the joints

Fig. 3a.

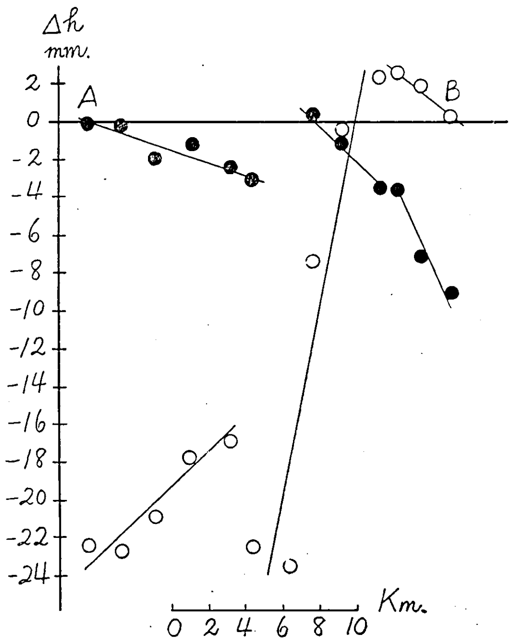


Fig. 3b.

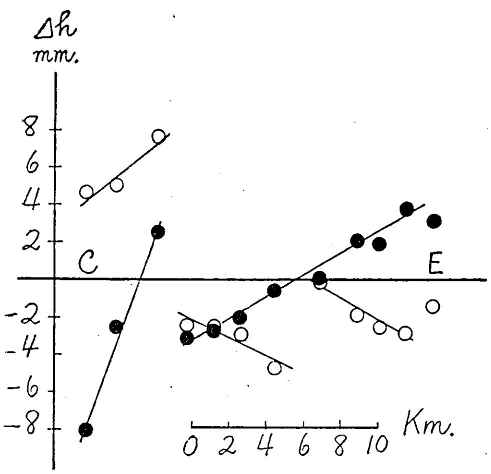
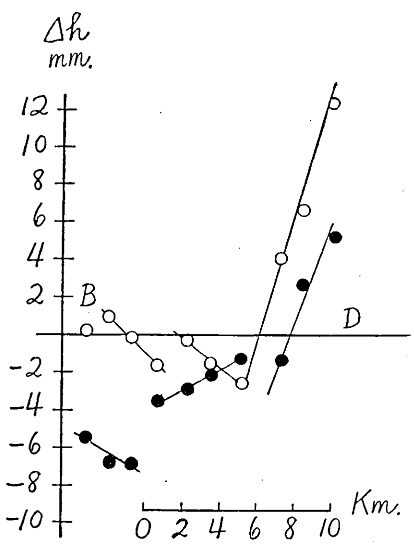


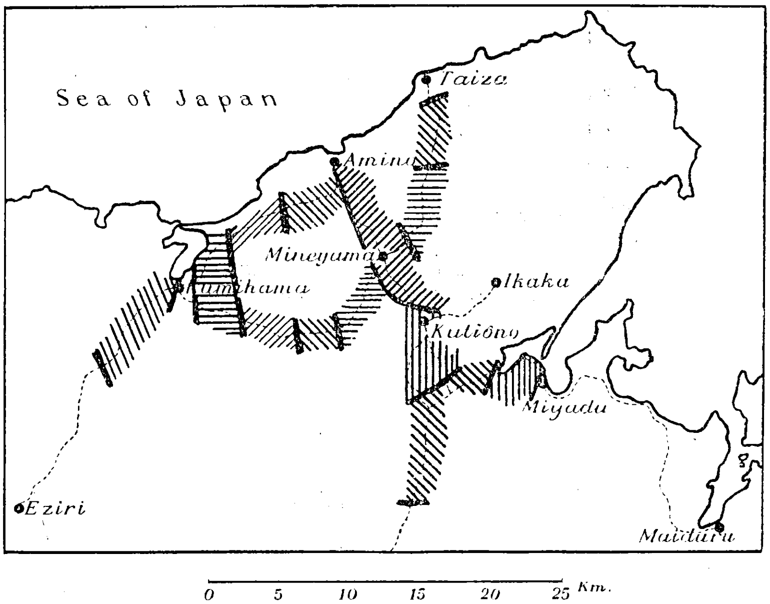
Fig. 3c.



of these segments occur at the same abscissæ for both series of graphs which correspond to different epochs of the levellings. The latter two facts are well elucidated by assuming that the ground in this district is made up of a number of discrete structural units, each of which behaves as a rigid body as a whole, being bordered with its neighbours by boundary lines corresponding to the joints of segments in the above figures.

The positions of the boundaries of these units as revealed by the above analysis are shown by thick lines in Fig. 4, each shaded part between two

Fig. 4.

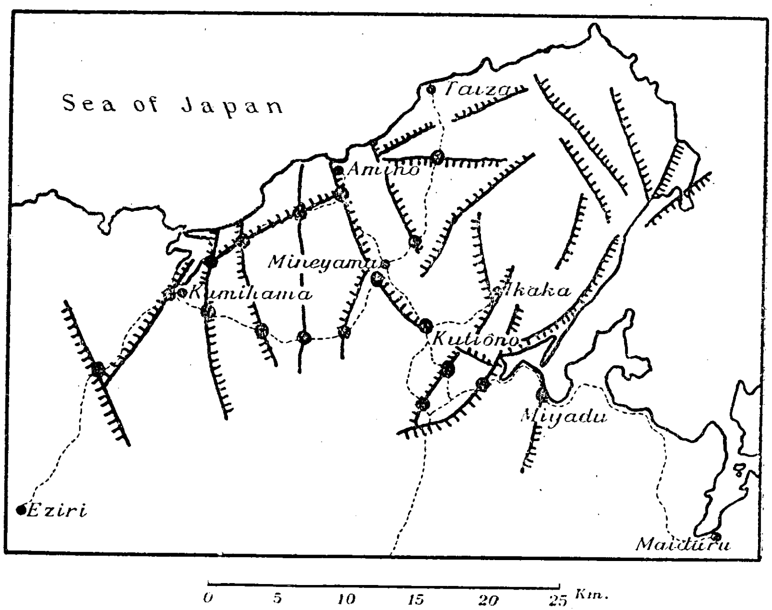


of these lines corresponding to a unit of structure of the ground. The bench marks lying on one and the same unit are rigidly connected to each other, being only subjected to the common tilting, upheaval, depression, etc., of the unit as a whole. In Fig. 3, the inclination of some of the structural units is seen to be inverted in sense for different epochs of the levellings. Each structural unit must have been able to move comparatively easily at least after the great earthquake.

7. After the structure of the Tango earthquake district has been ex-

plored by a *physical* method and a remarkable structural feature has been found, the *geological* data concerning the structure of this district will now be referred to, so as to get, if possible, a geological interpretation of the above feature. The geological structure of this district were investigated by many workers(1) who made visits to the district immediately after the earthquake. Through the efforts of these geologists, a number of young faults as well as geologically weak lines are found to run in different directions as shown in Fig. 5.

Fig. 5.



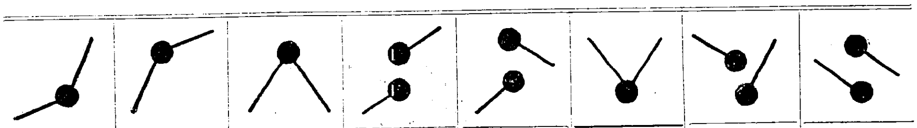
The levelling routes cross with several of these lines at the points marked by black dots as shown in Fig. 5. When the positions of these points are compared with those of boundary lines between the structural units in Fig. 4, a very close coincidence is found to exist between them.

(1) B. Kotô, Journ. Fac. Sci Tok. Imp. Univ., Sec. II, Vol. II, Part 6, (1928).
H. Tsuya, Bull. Earthq. Res. Inst., 4 (1928), 139.
K. Watanabe and H. Satô, Rep. Imp. Geol. Survey, No. 110 (1928).
F. Tada, Bull. Earthq. Res. Inst., 5 (1928), 111, etc.

What is inferred from this fact is that these young faults are still in their phase of activity and the intervening ground between any two of them behaves approximately as a block of rigid body. It is quite a remarkable fact that the tectonic structure of the crust still maintains its significance in such a momentary movement as is here dealt with.

8. The movements of the ground at the boundaries of the structural units may be classified into following types, of which the numbers of the case actually observed in the present study are shown in the second row under the corresponding entries.

Fig. 6.



0	1	1	0	1	5	1	5

9. A peculiar mode of the movements of the crust is found in the case illustrated in Fig. 3b. The existing two structural units were subjected to a common tilting in the earlier stage of the movements, before their respective and differential movements began in the later stage.

On the other hand, the geographical distribution of the epicenters of the after-shocks connected with the Tango earthquake was investigated by A. Imamura and N. Nasu.[1] According to their results, *no* earthquake was recorded whose epicentre lay near or along the boundary line between the two structural units now under consideration in the epoch when these two units began their respective movements. This is quite an important fact from which much may be suggested concerning the mechanism of occurence of an earthquake in special connection with the movements of the crust, though it will be premature to draw any definite conclusions out of this single datum.

10. Whether or not the activity of the young faults in the Tango

(1) A. Imamura and N. Nasu, Proc. Imp. Acad., 3 (1927), 227.
N. Nasu, Ibid., 4 (1928), 378.

district has been accelerated by the earthquake is not certain. There are, on the other hand, good many reasons to expect that the earth crust, especially in Japan, is in a state of perpetual movement. The rate of movement is often so rapid as to be well detected by a measurement with delicate instrument in an interval of several ten years.(1) It seems to be not improbable that when some subterranean geophysical agencies, if there are such things at all, once begin their activities in some localities, the block movements in the same localities may be accelerated as one of their results and at the same time an earthquake may occur in the same localities as another of their results. The latter two phenomena are then not causally connected with each other, but rather are the different manifestations of the action of the same subterranean agencies.

Aftr all, a literally *mosaic* structure of the earth crust was found in the Tango earthquake district and the movement of each of its structural elements was traced in some detail. The present writer was thus finally led to believe, with most geologists, that the earth crust with its discrete structural constituents is as ever in a state of perpetual movement and the phenomena of earthquake is nothing but an accidental manifestation of the activity of some subterranean agencies then prevailing in the earthquake district.

In the course of this study, the writer had much occasions to have talks about the present problem with Professors T. Terada, M. Ishimoto, S. Tsuboi, Messrs. F. Tada and H. Tsuya which were very useful for him. The writer wishes to express his best thanks and indebtness to these gentlemen for their kind advices and instructions. Finally he highly appreciates the elaborate works of the Land Survey Department of the Imperial Army which have made so great a contribution to the development of Seismology hardly to be overestimated.

October 1928.

---

(1) A. Imamura, Proc. Imp. Acad., 4 (1928), 56, 109.
N. Yamasaki, Ibid., 4 (1928), 60.