6. *Block Movements as Revealed by Means of Precise Levellings in Some Earthquake Districts of Japan.*

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1. Introduction.

It is of prime importance for the research of the factor determining earthquake occurence to learn the modes of the existing secular movements of the earth crust. It is, and there are good many reasons to be, believed, that the earth crust is even at present subjected to a slow but continual movement as it has been in geologic ages. The cumulative or integrated effect of these movements in a locality may be seen in its topographic and other physiographical features. If we remember, however, that the phenomenon of earthquake is nothing but an accidental manifestation of the geologic movement in the course of its present activity, the quantitative evidence of its differential, but not of its integrated, effect is urgently wanted. Regarded as a physical phenomenon, this movement, however, is exceedingly slow in its rate of progress, thus for the present purpose is required an extremely delicate instrument to make the measurement with and a very long interval of time to make the measurement through. With this object in view, the revisions of the triangulations and precise levellings have been made by the Land Survey Department of the Imperial Army since some decades of years after some of the severe earthquakes and volcanic eruptions over their respective disturbed areas. That we have at present not a few data available for the enunciated investigations is to be counted into the credit of the pioneer students of earthquake who duly payed their attentions to this direction and arranged the scheme of revisions and also of the Land Survey Department of the Imperial Army which actually practised the revisions. The results of these revisions have already been published in a number of reports and the discussions are also made of these results from many divergent points of view. In all of these levelling surveys, sensible changes in heights of bench marks are found to have taken place during the intervals between the successive levellings in which the events of the earthquakes or volcanic eruptions are involved. The relations between these movements and the geological structures of the district concerned, however, seem to have been unduly left untouched except in the case of Echigo and Shinano levellings which was discussed by Prof. N. Yamasaki[1] from a geological point of view. He emphasised that the chronic tilting of land blocks is actually detected in this case, of which the meaning is readily understood by the geological features of the district. K. Mutô[2] of the Land Survey Department also discussed the tilting of land blocks in the Kwantô district. The present writer has recently made some similar but more detailed examinations on the earth movements in some earthquake and volcanic districts in this country which seem to have hitherto been left untouched from this interesting point of view. In the following pages, the results of these examinations will be given in due sequence.

2. SHIMABARA EARTHQUAKE DISTRICT.

In connection with the great earthquake which devastated the Shimabara district in the Central Kyûshû on Dec. 8th, 1922, the revision of the precise levellings was made in the district in the next year of the catastroph. The object of this work was to detect vertical movements of the crust in this district which might have taken place since the older observations were made in 1894 and 1897. The results of the postseismic levellings when compared with the older ones will give the vertical movements of the crust, most of which is presumably directly associated with the very earthquake. The results of comparisons of the levellings are contained in the paper by Prof. A. Imamura.[3]

These results were subjected to a quite similar process of examination as was adopted by the present author in his research on the postseismic block movements in the Tango earthquake district.[4] The process adopted is as follows. Firstly, every conspicuous turning point of the levelling routes with a sharp bent was marked by A, B, C, etc., as is shown in Pl. I. Secondly, every pair of the consecutive points was connected by a segment of straight line. Thirdly, the position of every bench mark between these

1) N. YAMASAKI, *Proc. Imp. Acad.,* 4 (1928), 60.

2) Read at the Monthly Meeting of this Institute, May 22nd, 1928. He pointed out for the first time, that the secular tiltings of land blocks are found by the comparison of two successive levellings.

3) A. IMAMURA, *Bull. Imp. Earthq. Inv. Comm.,* **10** (1928), 63.

4) C. TSUBOI, *Proc. Imp. Acad.,* 4 (1928), 529.
Bull. Earthq. Res. Inst., **6** (1929), 74.

two points was normally projected upon the segment which connects the two. Fourthly and finally, taking these projections along the horizontal axis, the vertical displacement Δh of a bench mark was represented by a point with its ordinate taken proportional to Δh. A few examples of the diagrams thus obtained are shown in Figs. 1 and 2. The positions of the bench marks may

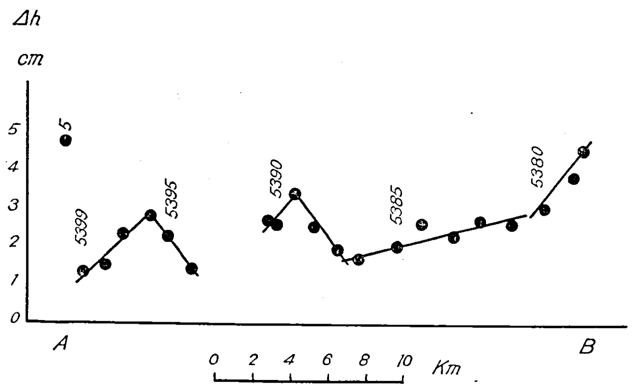


Fig. 1.

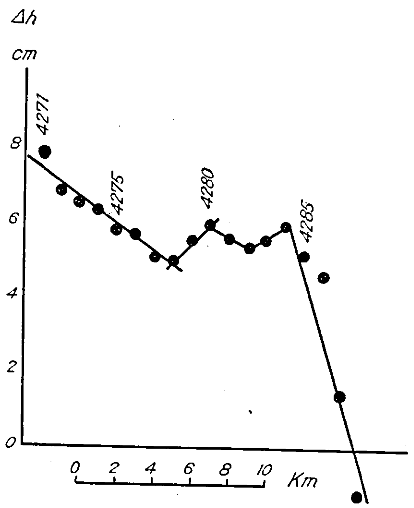


Fig. 2.

be identified by the reference to Pl. I. In making these diagrams, the zero of the ordinate is assumed arbitrarily. No loss in generality in the following discussions is, of course, introduced by this assumption.

Remarkable features will be found in the manner of distribution of the points in the diagrams. These points illustrating the changes of heights of the bench marks lie neither on a smooth nor on an irregular curve but they lie on a number of broken segments of straight lines. These characteristic facts may well be elucidated by assuming that the earth crust in this district is made up of a number of descrete structural units, each of which behaves approximately as a rigid body as a whole. Each of these units is bordered by its neighbours along the boundary lines corresponding to the joints of segments of straight lines in the graphs. The geographical positions of the boundary lines of these units as revealed by the above analysis are indicated by thick lines in Pl. I, each coloured part between two of these lines correcponding to an elementaly unit of structure of the crust. The bench marks lying on one and the same unit are, thus, rigidly connected to each other, being only subjected to a common tilting, upheaval, depression of the unit as a whole.

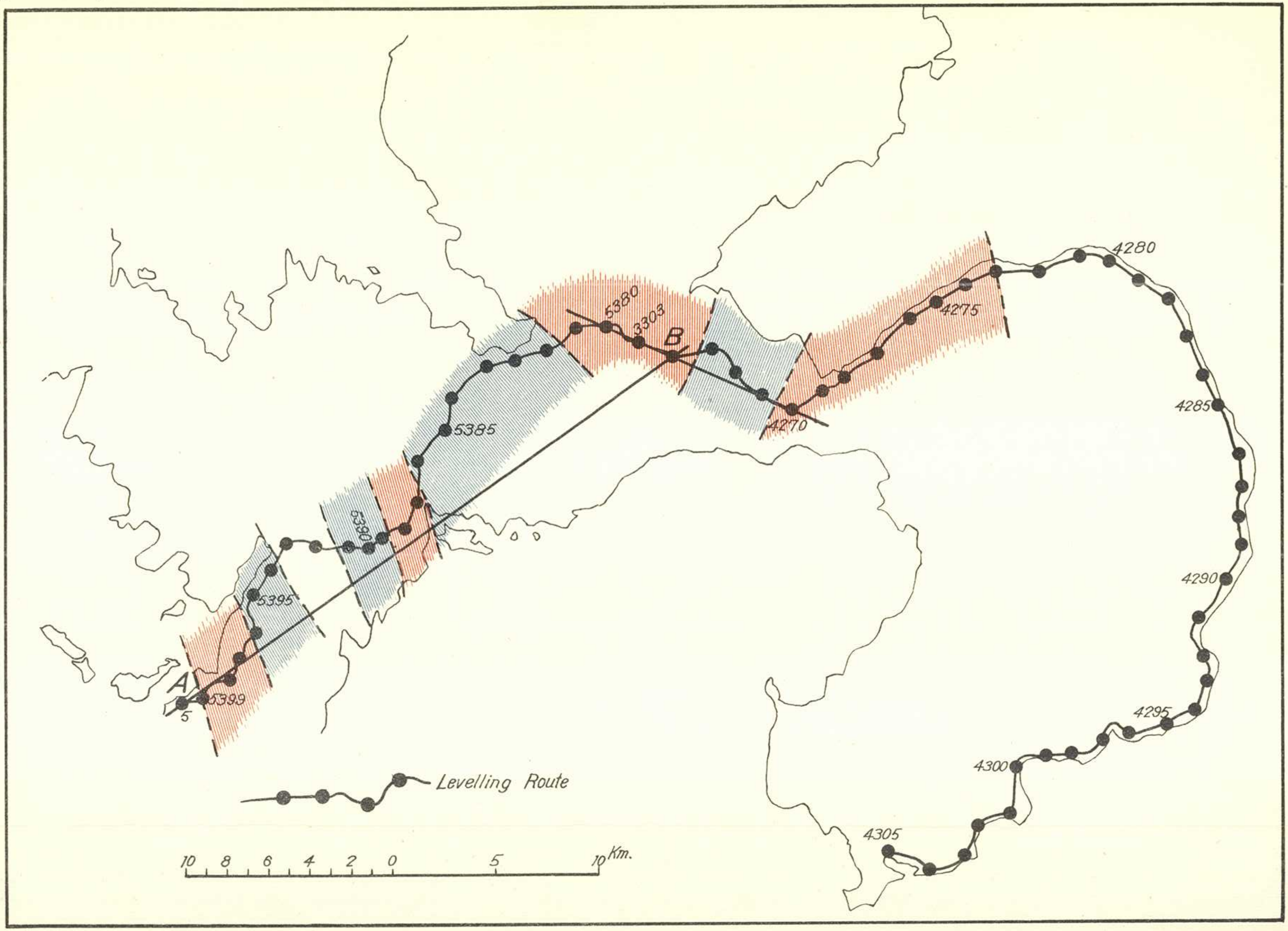
On the other hand, it is accepted that the earth crust in some district is run through by a number of faults, being devided into what is called land blocks. That these geological land blocks actually correspond to what we have called the structural units in the above will be obvious, if we refer to the topography and the geology of this Shimabara district.

3. Sakurajima Volcanic District.

A great eruption took place on Jan. 12th, 1914 of the volcano Sakurajima in the Southern Kyûshû. In view of getting, if possible, some informations regarding the deformation of the earth crust caused by this eruption in the neighbourhood of the volcano, the revision of the precise levellings was made around the volcano. The results were compared with those of the older surveys which were done in 1891–1898. The descrepancies between the two levellings give the vertical movement of the crust probably associated with the eruption. A part of the levelling route which runs close to the volcano was again covered by another series of precise levellings in February of 1915. The difference of the second and the third levellings gives the vertical movement of the crust in the interval of about one year after the eruption.

The results of levellings are contained in the comprehensive work of Prof. F. Omori[5] on the eruption of this volcano. These results were examined just in the same manner as in the former cases. The graphs shown in Fig. 3 represent the vertical displacements of the bench marks in this district. In these graphs, the mark ○ corresponds to the difference in height

5) F. Omori, *Bull. Imp. Earthq. Inv. Comm.*, 8 (1914–1922), 50.



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between the first and the second levellings while the mark • to that between the second and the third. In these graphs, the characteristic linear distribution of the points is also clearly seen as in the former cases. Moreover, a remarkable fact is found in these graphs that two series of graphs, though entirely different in their absolute magnitudes, are of quite similar form. The joints of the segments of straight lines occur at the same abscissa for both series of the graphs which correspond to different epochs of the levellings. This fact may be regarded as a sufficient support for the statement that the characteristic features in the distribution of the points are not due to a mere accidental play of chance nor due to errors in the observation of the surveys, but are due to some real physical causes, and that the boundary lines of the assumed land blocks which correspond to the joints of the segments have important significances connected with the geological structures of the district concerned.

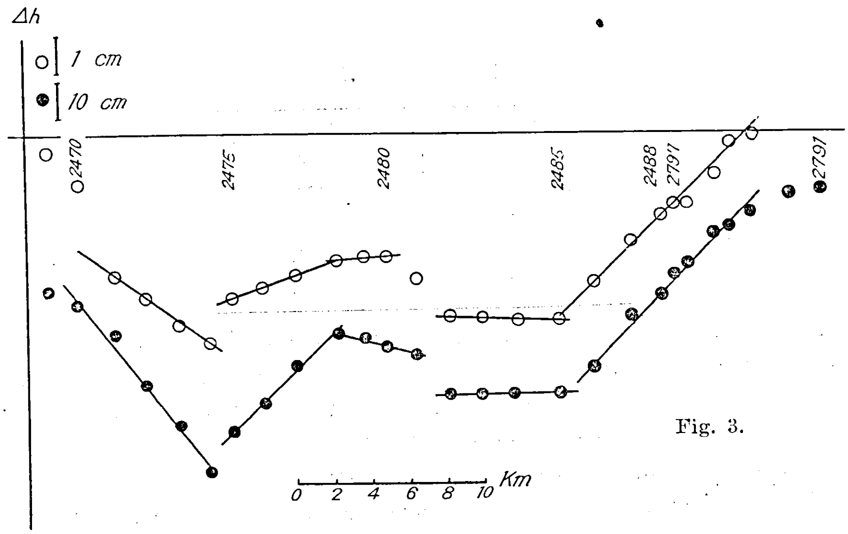


Fig. 3.

In discussing the results of these levellings, Prof. F. Omori pointed out the fact that there is a general depression of the crust which gradually decreases with the increasing distance from the centre of the volcano. In the great eruption of this volcano, an immence quantity of lava overflowed the crator which is estimated to be about 3×10^{15} gr. by Prof. B. Kotô.[6] This immense mass will disturb the initial gravitational field in its neighbourhood and the plumb lines will be slightly directed towards this mass. The angle

6) B. Kotô, *Journ. Col. Sci. Tokyo Imp. Univ.*, 38 (1916), 107.

of deflection of the plumb line caused by this disturbance is given by

$$\alpha=\frac{km}{r^2g},$$

where k is the gravitational constant
m the mass of the lava
r the distance from the mass
g the accerelation due to gravity.

In response to these deflections of plumb lines, the bench mark at x appears as if it has been subjected to a depression of amount Δh such that

$$\left|\Delta h\right|=\left|\int_{\infty}^{x}\frac{km}{r^2g}dr\right|=\frac{km}{gx}$$

if the levelling is carried out along a route from an infinite distance up to the distance x from the lava mass. Roughly putting $k=6\times10^{-8}$, $m=3\times10^{15}$, $g=10^3$, we have the following relation between $|\Delta h|$ and x.

TABELE I.

x (cm.)	Δh (cm.)
10^1	18000
10^2	1800
10^3	180
10^4	18
10^5	1.8
10^6	0.18

As is seen in the above calculation, this amount is not large enough to account for the general "depression" actually observed around Sakurajima. It must be remembered, however, that here the mass which came out of the crator only is taken into consideration, but not the subterranean mass change which must have taken place with the eruption.

On the other hand, the effect of loading by the mass of lava may also yields the general depression. A part of the observed general depression in the neighbourhood of Sakurajima may indeed be due to this circumstance. Superposed on these general depression, we have seen that the individual tiltings of some land blocks took place.

In the present case, the bench marks are two-dimensionally distributed over the disturbed area, so that the magnitudes and directions of tilting of some of the land blocks can be calculated. Thus for instance, bench marks 2486, 2487, 2488, 2797, 2796, 2795, 2794, 2793, 2792, 2489, 2490, 2491 lie on one and the same land block. Given the co-ordinates of these bench marks and their respective vertical displacements, the magnitude and direction of tilting of the block were calculated by the method of least square. By this method, it was found that this block tilted down towards the direction N 72°50′ W by the amount of 9″. The vertical displacements of the bench marks calculated by this assumption are compared with the observed values in the following table.

TABELE II.

Bench Mark	Δh obs.	Δh calc.
	mm.	mm.
2486	−616	−580
2487	−485	−495
2488	−421	−411
2797	−369	−370
2796	−338	−358
2795	−260	−293
2794	−244	−261
2793	−206	−196
2792	−155	−108
2789	−348	−365
2490	−301	−308
2491	−306	−291

Good agreements between these values are seen proving the correctness of our present suppositions. Similarly, the directions and the magnitudes of inclinations of two other blocks were calculated, with the results shown in the following tables.

TABELE III.

Bench Mark	Δh obs.	Δh calc.
	mm.	mm.
2505	−174	−143
2504	−207	−200
2503	−242	−280
2502	−314	−302
2501	−379	−393
2499	−468	−430
2498	−401	−395
2497	−363	−351
2496	−344	−367

Direction of tilting .... N 30° 40′ W
Magnitude of tilting .... 10″

TABELE IV.

Bench Mark	Δh obs.	Δh calc.
	mm.	mm.
2463	−259	−270
2464	−291	−311
2465	−291	−380
2466	−302	−292
2469	−407	−370
2470	−446	−468
2471	−527	−563
2472	−658	−677
2473	−770	−756
2474	−894	−846

Direction of tilting .... N 57° 40′ E
Magnitude of tilting .... 12″

In the Pl. II, the tilting of these land blocks are represented by the arrows drawn in the direction of depression with their lengths taken proportional to the amount of tilting. The three arrows are seen to converge towards a point somewhat to the north of the volcanic crator. The aggregates of land blocks subjected to a general depression may have behaved as shown in the accompanying diagramatic figure.

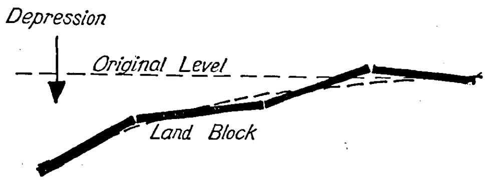
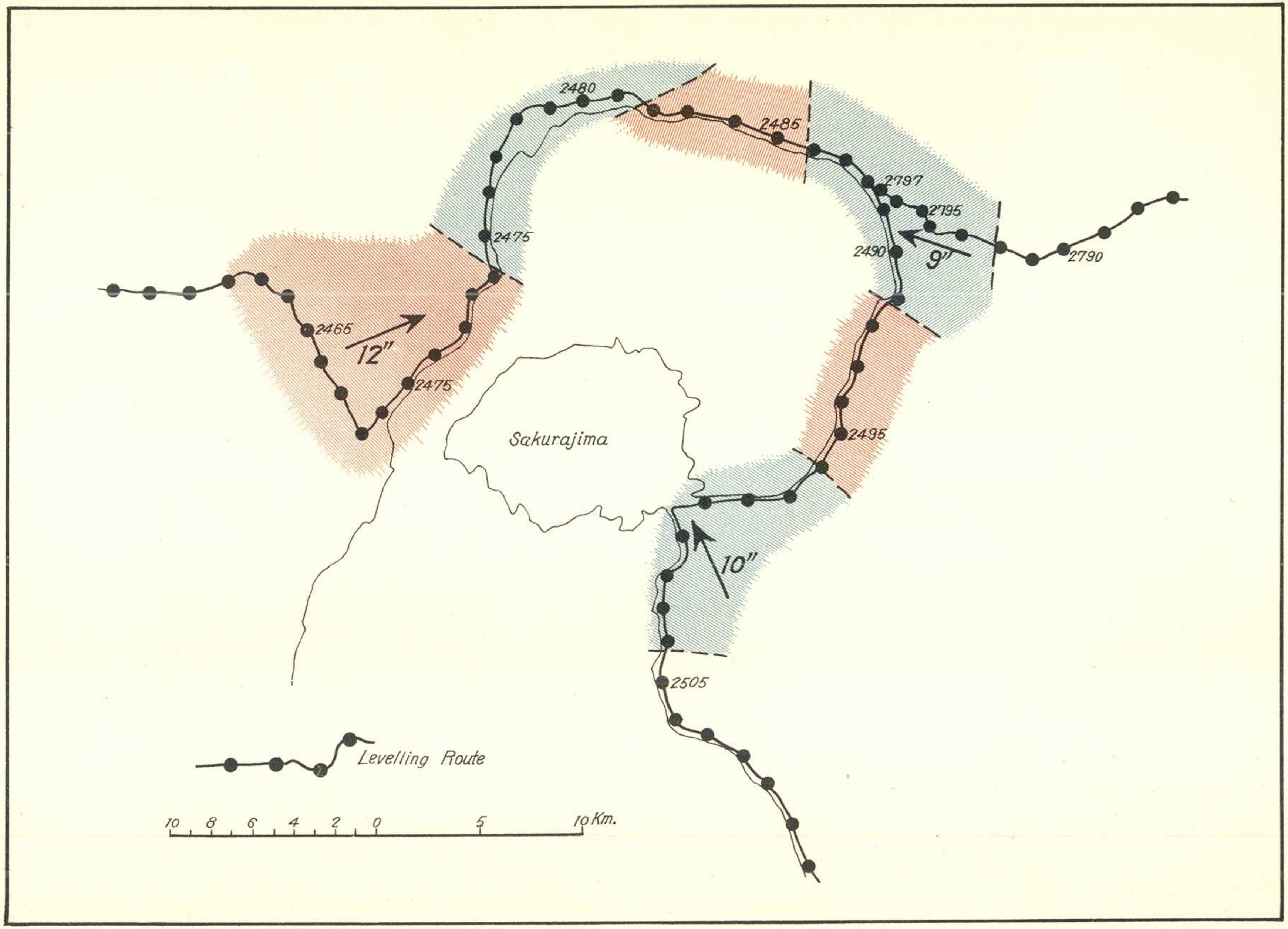


Fig. 4.

4. MINO OWARI EARTHQUAKE DISTRICT.

A great earthquake took place on Oct. 28th, 1891 in Mino Owari districts of Central Honshû. In this earthquake, a well-known great fault was formed whose trend is, according to Prof. K. Kotô, in good agreement with a line of geological significance. In this case also, a revision of levelling surveys was carried out over the disturbed area. The changes of heights of the crust in the interval of two levellings are graphically shown in Figs. 5 and 6, just in the same manner as in former cases. In this case also, some block movements are seen to have clearly taken place. (Pl. III).



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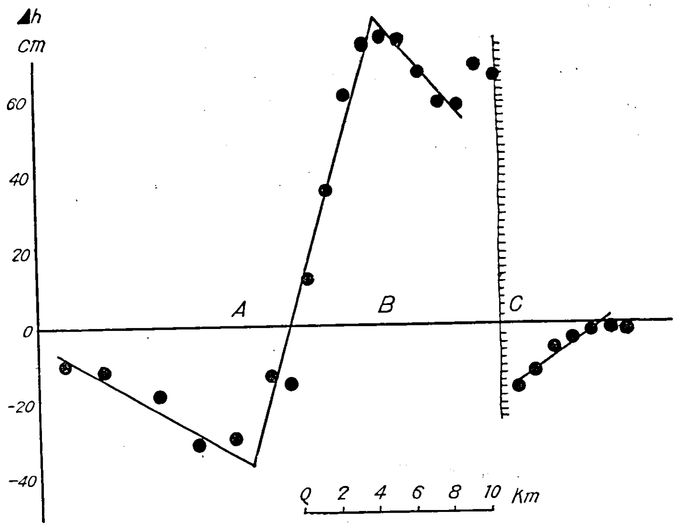


Fig. 5.

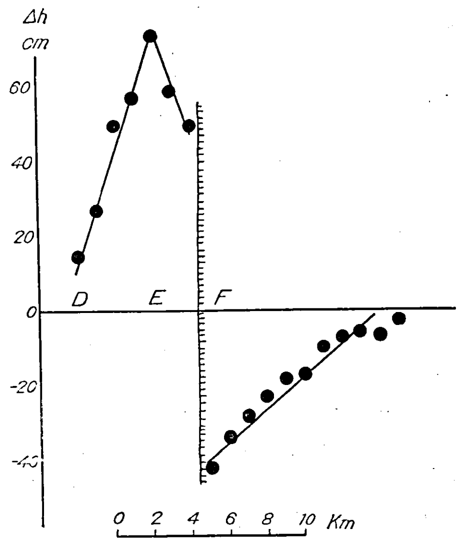


Fig. 6.

5. Tajima and Tango Earthquake Districts.

In an interval of about a couple of years, two great earthquakes took place in the Tango and Tajima districts. The Tajima earthquake took place on May 23rd, 1925, and the Tango earthquake on March 7th, 1927. Their epicentres were only 20 km. apart from each other. After these earthquakes, the revisions of precise levellings were extended to the areas affected by these earthquakes.[7] A part of the results of the investigation made have already been published.[8] The results of examination made for the Tajima district are seen in the following Fig.7. Here also the block movements are seen to have taken place. (Pl. IV).

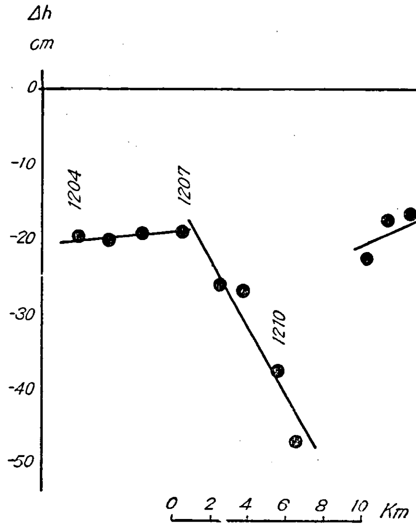
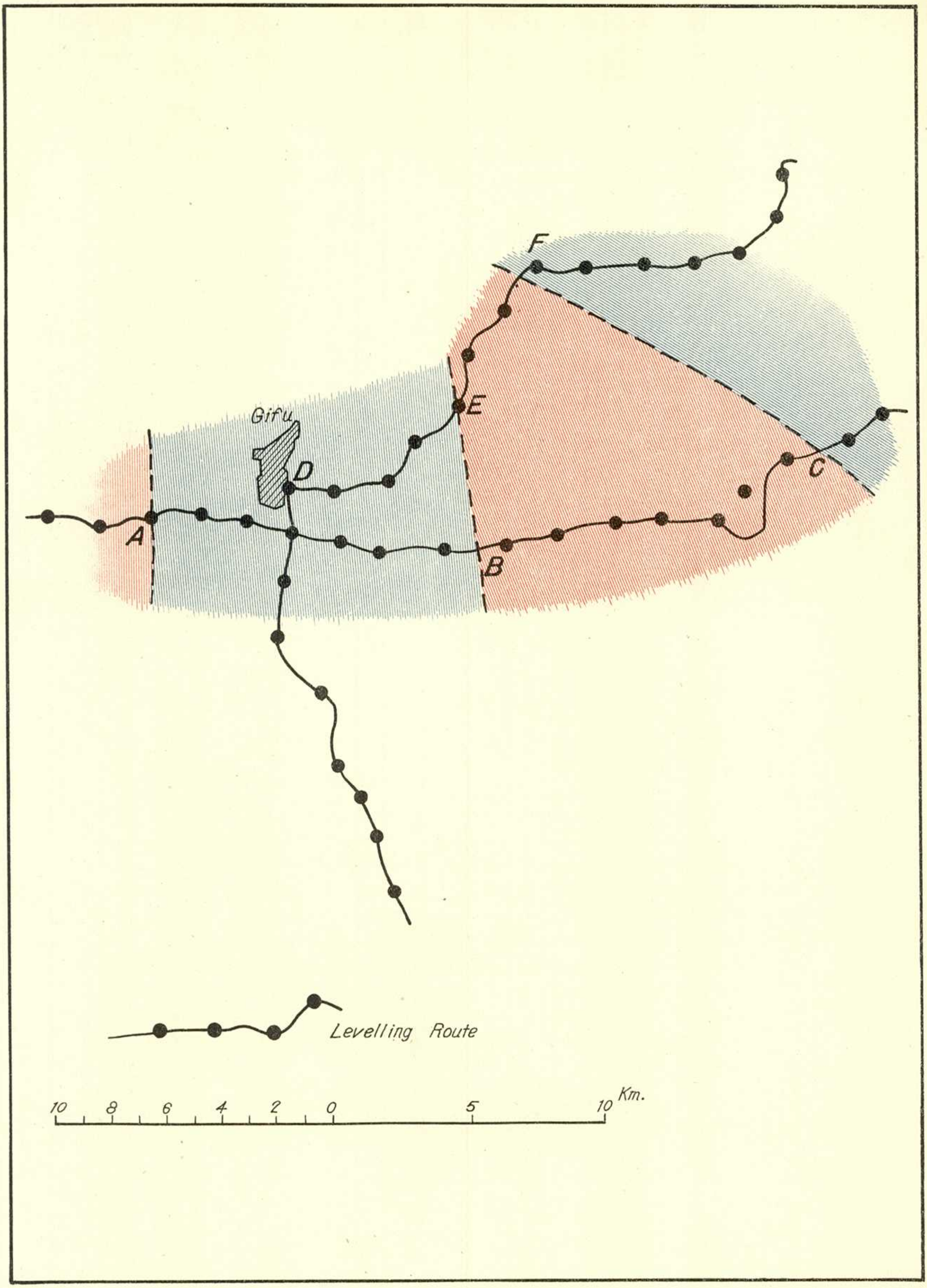


Fig. 7.

6. DISCUSSIONS.

After all, the present author believes to have succeeded in demonstrating the actual manifestation of the existing geological movements in some localities of this country. It has become clear that the land blocks still preserves their physical significance in geologically instantaneous and minute movements of so short a duration as may be counted in scale of years. Such being the structure, there seems many problems to be reviewed under a new postulate regarding the physical, especially mechanical, properties of the earth crust in somewhat a different manner from what has hitherto been accepted. Can any elastic stress of major scale due to some geological forces really exist in the earth crust with so much structural cosntituents? The

7) A. IMAMURA, *Bull. Imp. Earthq. Inv. Comm.*, **10** (1922–1928), 71.
8) C. TSUBOI, *Proc. Imp. Acad.*, **4** (1928), 529.
Bull. Earthq. Res. Inst., **6** (1929), 74.



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Land Blacks in the Mino-Owari District.

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characteristic behaviour displayed by a medium with aggregate constituents is well-known. The most conspicuous example is furnished by the pile of sand. The experiments of T. Terada and N. Miyabe[9] regarding the deformation of sand pile afford us brilliant examples. If the physical properties of the earth crust are not entirely analogous with those of the sand pile, there seems no doubt that the statical elastic stress extending to infinity cannot exist in the earth crust. The earth crust may be regarded under a certain class of force as an aggregate of wooden blocks floating on a liquid in contact with each other by their lateral faces. Putting aside the problem regarding the position of the source of generation of the train of seismic disturbances, the whole system of the land blocks in the earthquake district must be subjected to a general slow displacement at the moment of the earthquake occurrence, each of the blocks being in mutual coupling with others. Let there be considered three land blocks A, B, and C in successive arrangement. Suppose they were disturbed by an earthquake and let the diplacement in the boundary A and B be small but discontinuous and that in the boundary of B and C large but continuous. In such cases, a passing field observation will only reveal the existence of the discontinuity of the displacement between A and B—what is called a fault. It has been usual in such cases to lay much stress on this visible discontinuity and to take this as a unique significant phenomenon concerning the earthquake. But how could we attribute the prime importance to the discontinuity between A and B if we could only know that the absolute displacement between B and C was far much larger? The *chaos* of the block movements as a whole, but not each of the differential movements at the boundary lines of the blocks appears to be the most characteristic and important phenomenon in the district of earthquake origin.

In conclusion, the present writer wishes to express his gratitudes to Professor Torahiko Terada for much suggestive instructions and helpful critisisms he has constantly given.

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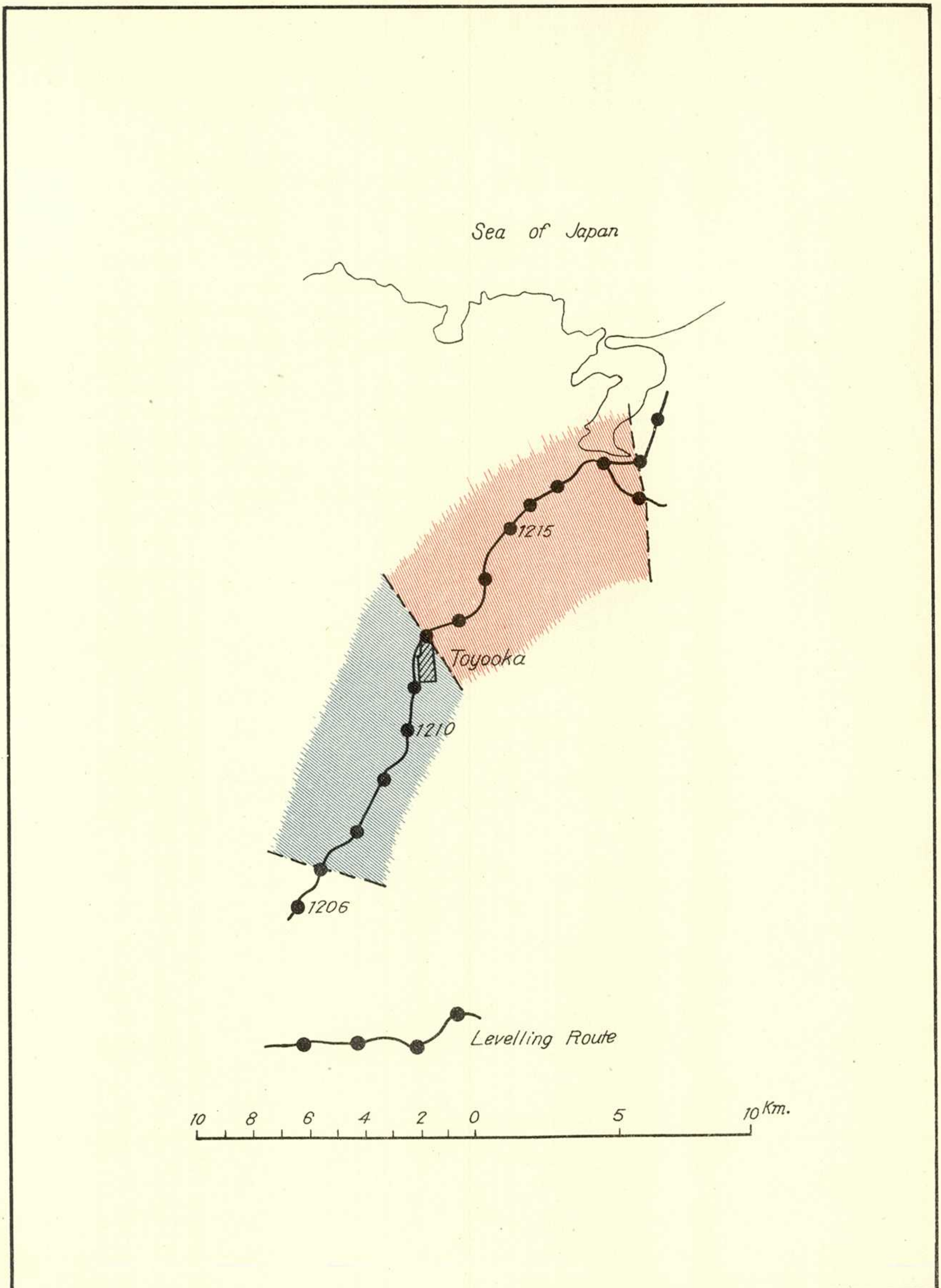
9) T. Terada, and N. Miyabe, *Bull. Earthq. Res. Inst.*, **4** (1928), 33; **6** (1929), 109.

6. 水準測量に依りて見出されたる地塊運動に就いて

地震研究所 坪井忠二

地震發生の本源を考へるに就いては、現在地殼が如何なる變動をなしつつあるかと云ふ事を明にするのが肝要である。我が國に於いては、明治二十四年の濃尾地震以來、大地震、大噴火のあつた毎に該地方の三角測量や水準測量の改測が行はれて來た。此の論文は、夫等の改測によつて明にされた地殼の變動を詳しく調査したものであつて、夫等の改測の結果、所謂地塊運動が明に見出される事を强張したものである。尙之等の物理的の方法で求められた地塊が、地質構造から見た地塊と一致するものである事は、著者の前論文で指摘した所であるが、此の論文に於いても此の見解が確められた。地殼が此の樣な片々的な構造を持つて居るものとすれば、それに彈性的ストレスが存在し得るやと云ふ點に就いても疑問を生ずるのであるが、著者は寧ろ之を否定する樣に傾いて居る。地震の際に生ずる所謂斷層は、唯二地塊の運動が不連續であつたと云ふ所に過ぎず、其の附近には連續ながらもつと大なる變移もあり得るわけであるから、只肉眼の野外觀察で發見し得る斷層よりも、地震地方の地塊全體としての動きと云ふものの方がより重大な意義を持つて居るのであらうと考へられる。



Land Blocks in the Tajima District.