42. *Crustal Deformations in Central Taiwan. Part 2.*

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1. In their preceding paper, two of the present writers, Hukunaga and Sato, dealt with the crustal·deformations in Central Taiwan based on the data of horizontal displacements of primary triangulation points and the vertical displacements of bench-marks on the lines of levels traversing the region under consideration.[1]

Since then a re-triangulation of the secondary and tertiary triangulation points distributed in the same region has been done, as a result of which the horizontal and vertical displacements of the secondary and tertiary triangulation points were measured.[2]

In the present paper, the writers discuss, in greater detail than in the last, the modes of crustal deformations in the regions that were most disturbed by the destructive earthquake of 1935, with the data of the horizontal and vertical displacements of the secondary and tertiary triangulation points as reference.

Since, in determining the positions of tertiary triangulation points, the Military Land Survey measured them with reference to the primary triangulation points, the horizontal displacements of the tertiary triangulation points are affected considerably by displacements of the surrounding primary triangulation points, with the result that the general mode of crustal deformation as studied by using the data of displacements of the secondary and tertiary triangulation points is not likely to differ much from that obtained by a study of the displacements of the primary triangulation points, as given in the preceding paper (Part 1).

In this paper, the crustal deformations are discussed in greater detail, particularly in connection with the active faults that appeared at the time of the destructive earthquake, based on the data of displacements of the secondary and tertiary triangulation points,[3] as will

1) M. SATO and M. HUKUNAGA, *Bull. Earthq. Res. Inst.*, **16** (1938), 300—316.
2) Report of the Military Land Survey issued in 1936.
3) The distribution of horizontal displacements of the triangulation points, which were used as data in the present study, is shown reproduced in Fig. 1.

now be shown.

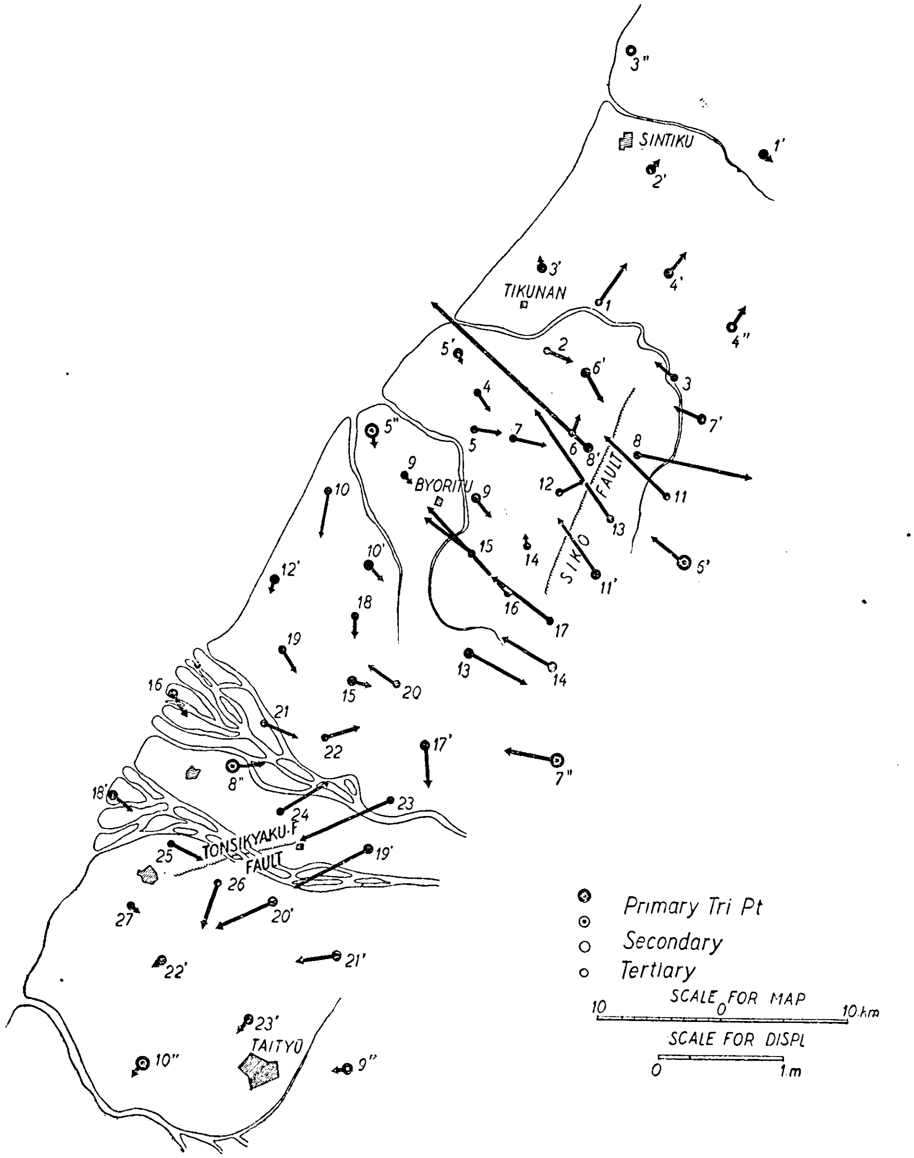

Fig. 1. Distribution of horizontal displacements.

2. The values of the components of the horizontal strains in the region under consideration were calculated by the method already used in calculating the horizontal strains in other regions.[4] The values of the horizontal divergence, rotation, etc., thus calculated for each of

4) T. TERADA and N. MIYABE, *Bull. Earthq. Res. Inst.*, **7** (1929), 283~240.

the triangular areas, with the triangulation points at their vertices, are given in Table I.

Table I. Horizontal strains in 10^{-5}.

Triangle	Δ	ω	S_m	γ_1	γ_2	θ_1
3″— 1′— 2′	− 0·5	− 0·2	2·2	1·7	− 2·7	−34°
3″— 2′— 2′	1·0	0·5	2·0	3·0	− 1·0	− 5
1′ — 2′— 4′	− 0·9	0·1	2·8	1·9	− 3·7	−31
2′ — 3′— 4′	1·1	0·8	2·5	3·6	− 1·4	− 5
4″— 1′— 4′	− 2·4	− 0·1	1·1	− 1·3	− 3·5	−30
4″— 4′— 1	− 4·2	− 0·8	3·2	− 1·0	− 7·4	−21
4′ — 3′— 1	− 4·8	2·5	9·2	4·4	−14·0	−11
3′ — 1 — 2	6·6	4·4	3·3	9·9	3·3	58
3′ — 5′— 2	5·1	1·6	3·1	8·2	2·0	−46
1 — 2 — 6′	9·4	− 0·7	12·8	22·2	− 3·4	85
4′ — 1 — 6′	10·4	− 1·3	11·6	22·0	− 1·2	88
4″— 3 — 6′	− 7·2	− 3·2	16·0	8·8	−23·2	48
4″— 3′— 7′	3·5	− 2·1	4·6	8·1	− 1·1	36
7′ — 3 —11	− 1·3	− 4·5	5·3	4·0	− 6·0	−12
3 —11 —13	− 2·5	− 7·5	5·5	3·0	− 8·0	− 8
3 — 6 —13	−15·8	− 0·8	13·0	− 2·8	−28·8	40
3 — 6 — 6′	−12·5	1·3	8·1	− 4·4	−20·6	30
6′ — 2 — 6	− 7·9	− 4·6	6·8	− 1·1	−14·7	− 9
2 — 6 — 7	− 7·4	1·9	6·7	− 0·7	−14·1	55
2 — 4 — 7	1·7	2·0	4·1	5·8	− 2·4	− 5
2 — 4 — 5′	4·2	0·6	2·3	6·5	1·9	−35
5″— 5′— 5	2·3	2·2	3·9	6·2	− 1·6	−11
5″— 5 — 9	2·1	0·3	4·1	6·2	− 2·0	20
5″— 9 —10	3·7	1·8	4·9	8·6	− 1·2	46
5 — 9 — 9′	4·2	− 1·3	1·2	5·4	3·0	64
5 — 7 — 9′	3·9	− 1·4	2·3	6·2	1·6	59
7 —12 — 9′	0·7	0·5	6·8	7·5	− 6·1	41
6 — 7 —12	− 4·1	3·2	4·7	0·6	− 8·8	76
6 —12 —13	−24·0	8·4	28·2	4·2	−52·2	63
6″—11 —13	5·1	− 3·4	13·5	18·6	− 8·4	− 40
6″—11′—13	12·2	0·0	15·5	27·7	− 3·3	− 60
11′ —13 —14	0·0	12·5	20·6	20·6	−20·6	67
12 —13 —14	−26·7	0·0	29·3	2·6	−56·0	52
9′ —12 —14	− 1·7	− 0·1	8·4	6·7	−10·1	34
9′ —14 —15	3·8	− 6·7	11·0	14·8	− 7·2	19
9′ —10′—15	− 4·9	0·2	4·6	− 0·3	− 9·5	31
9′ —10′— 9	2·0	0·2	2·2	4·2	− 0·2	−48

(*to be continued.*)

Table I. (*continued.*)

Triangle	Δ	ω	S_m	γ_1	γ_2	θ_1
10′—9—10	0·9	3·4	4·4	5·3	−3·5	19°
10′—12′—10	−0·8	1·4	6·6	5 8	−7·4	−3
10′—12′—18	−1·9	−1·8	5·0	3·1	−6·9	75
10′—14—18	−0·5	−0·8	5·5	5·0	−6·0	57
14—16—18	−26·7	−5·0	31·8	5·1	−58·5	39
14—15—16	−7·6	−8·4	23·9	16·3	−31·5	15
14—16—11′	−20·4	−7·1	24·0	3 6	−44·4	18
11′—16—17	12·6	−3·1	6·9	19·5	5·7	−63
14′—16—17	5·6	−8·9	22·2	27·8	−16·6	−46
14′—13′—16	0·0	7·3	25·4	25·4	−25·4	−84
13′—16—18	18·6	18·7	36·4	55·0	−17·8	−63
10′—13′—18	6·8	−1·2	4·6	11·4	2·2	10
12′—18—19	4·0	1·0	3·3	7·3	0·7	−31
12′—16′—19	2·1	1·0	3·0	5·1	−0·9	−48
15′—18—19	−2·8	2·2	3·2	0·4	−6·0	−22
13′—15′—18	1·7	1·0	8·0	9·7	−6·3	−18
13′—17′—20	18·8	−4·8	10·6	29·4	8·2	−28
13′—15′—17′	3·8	−3·8	2·4	6·2	1·4	50
13′—14′—17′	−11·7	−1·7	18·6	6·9	−30·3	58
7′—14′—17′	−2·0	2·2	7·8	5·8	−9·8	77
15′—17′—22	−3·7	−2·1	6·3	2·6	−10·0	−55
15′—19—22	−3·2	1·5	3·6	0·4	−6·8	−12
19—21—92	−2·4	3·1	1·4	1·0	−3·8	23
16′—19—21	0·1	1·8	3·4	3·5	−3·3	−26
8″—16′—21	−1·2	0·1	5·4	4·2	−6·6	−5
8″—16′—18′	0·0	1·6	2·9	2·9	−2·9	9
8″—21—22	−4·9	1·0	5·9	1·0	−10·8	15
17′—22—23	−1·2	−12·5	16·6	15·4	−17·8	58
19′—22—23	−14·5	−4·5	18·8	4·3	−33·3	−87
19′—22—24	−9·6	−5·9	12·5	2·9	−22·1	−86
8″—22—24	−3·2	2·6	5·2	2·0	−8·4	−1
8″—24—25	0·7	3·1	4·9	5·6	−4·2	22
8″—18′—25	2·6	1·2	0·4	3·0	2·2	31
18′—25—27	2·5	−1·6	4·3	6·8	−1·8	4
24—25—26	8·0	−4·6	16·0	24·0	−8·0	69
20′—24—26	3·8	−3·5	20·5	24·3	−16·7	59
19′—20′—24	−3·3	−8·8	18·2	14·9	−21·5	78
19′—20′—21′	−3·2	−1·8	4·2	1·0	−7·4	−19
25—26—27	−3·0	−6·3	7·0	4·0	−10·0	87
22′—26—27	−5·1	−2·8	3·0	−2·1	−8·1	−56

(*to be continued.*)

Table I. (*continued.*)

Triangle	Δ	ω	S_m	γ_1	γ_2	θ_1
20′ —22′—26	−10·9	− 0·8	4·3	− 6·6	−15·2	47°
20′ —22′—23′	− 3·2	1·0	4·9	1·7	− 8·1	−55
20′ —21′—23′	− 2·1	2·8	1·9	− 0·2	− 4·0	−34
9″—21′—23′	− 1·8	1·8	2·1	0·3	− 3·9	−66
10″—22′—23	0·1	− 0·2	1·1	1·8	− 0·4	−85

The geographical distributions of these horizontal strains, i. e. divergence Δ, rotation ω, maximum shear S_m, and the principal strains γ_1, γ_2, are shown in Figs. 2∼5, respectively.

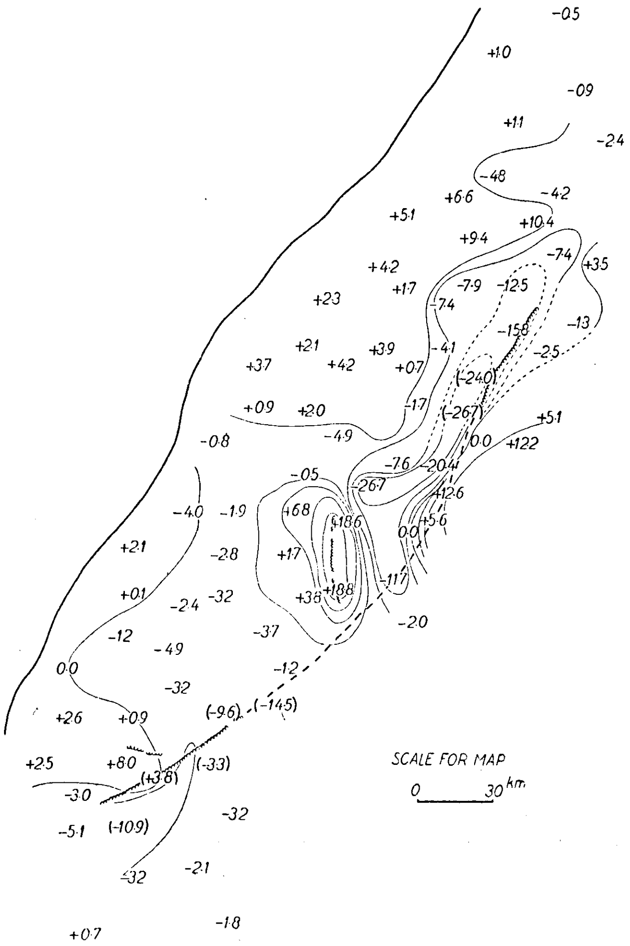

Fig. 2. Distribution of Δ.

In drawing the lines of iso-Δ, and iso-S_m, as in Figs. 2 and

4, the values of the strains in areas traversed by active faults are neglected.

As to the distributions of these horizontal strains, shown in Figs.

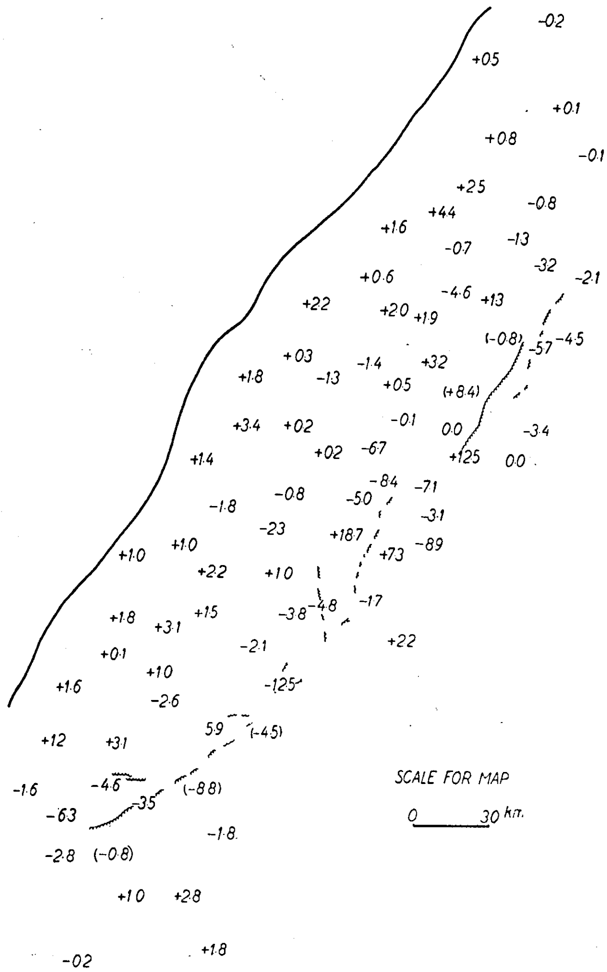

Fig. 3. Distribution of ω.

2∼5, the following points will be noticed.

(i) In the distribution of horizontal divergence, and of maximum shear, a zone of maximum disturbances was found on the western side of the Siko fault, parallel to the trend of the fault and close to it.

(ii) Upon extending the line that represents the trend of the active Siko fault southward to connect with the northeastern end of the line of the Tonsikyaku fault, the existence of which was also found at the time of the destructive earthquake of 1935, it was noticed that the

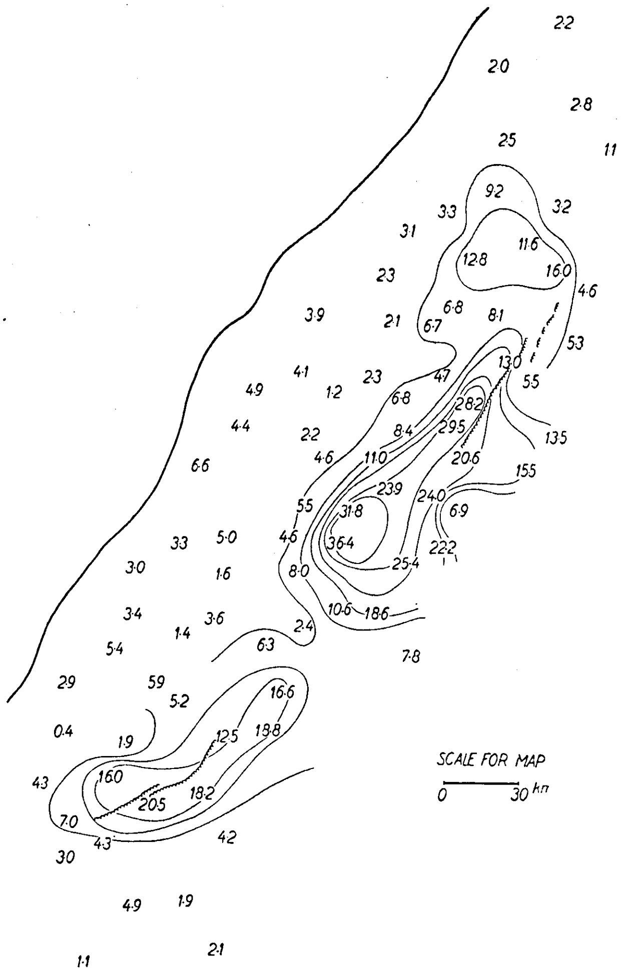

Fig. 4. Distribution of S_m.

zone of maximum disturbance is situated on the western side of the line that represents the estimated trend of the fault line, as shown by the dotted lines in Fig. 2.

(iii) The principal strain, especially compression, was greater in the region traversed by the dotted line, namely, the estimated southward extension of the Siko fault, where there are many traces of landslides that might have occurred at the time of the 1935 destructive earthquake.

The horizontal strain was also greater in the zone that includes the Tonsikyaku fault. This zone however extends symmetrically on both sides of the fault. Elsewhere in the region, the horizontal strain is

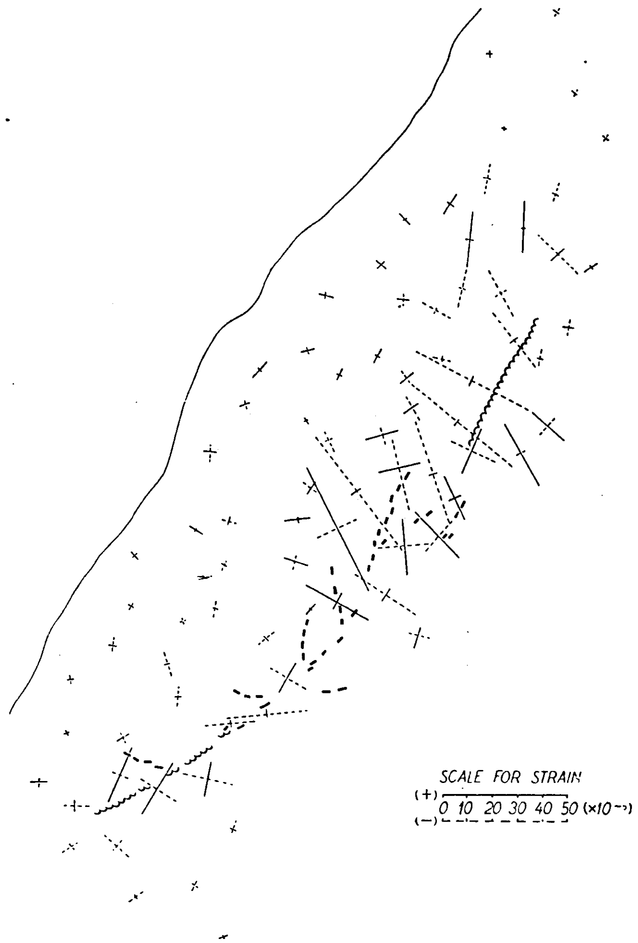

Fig. 5. Distribution of principal strain.

generally smaller, being of the order of 10^{-5} or less. In short, the crustal deformations, which are believed to have occurred in association with the destructive 1935 earthquake, were concentrated in a narrow zone on the western side of the Siko fault and on both sides of the Tonsikyaku fault.

3. In order to compare the horizontal crustal deformation with the vertical deformation, we have reproduced in Fig. 6 the distribution of the vertical displacements of the secondary and tertiary triangulation points.

In comparing this figure with Fig. 2, which latter shows the distribution of the horizontal divergence, it was found that the region of remarkable contraction situated west of the line of the Siko fault was

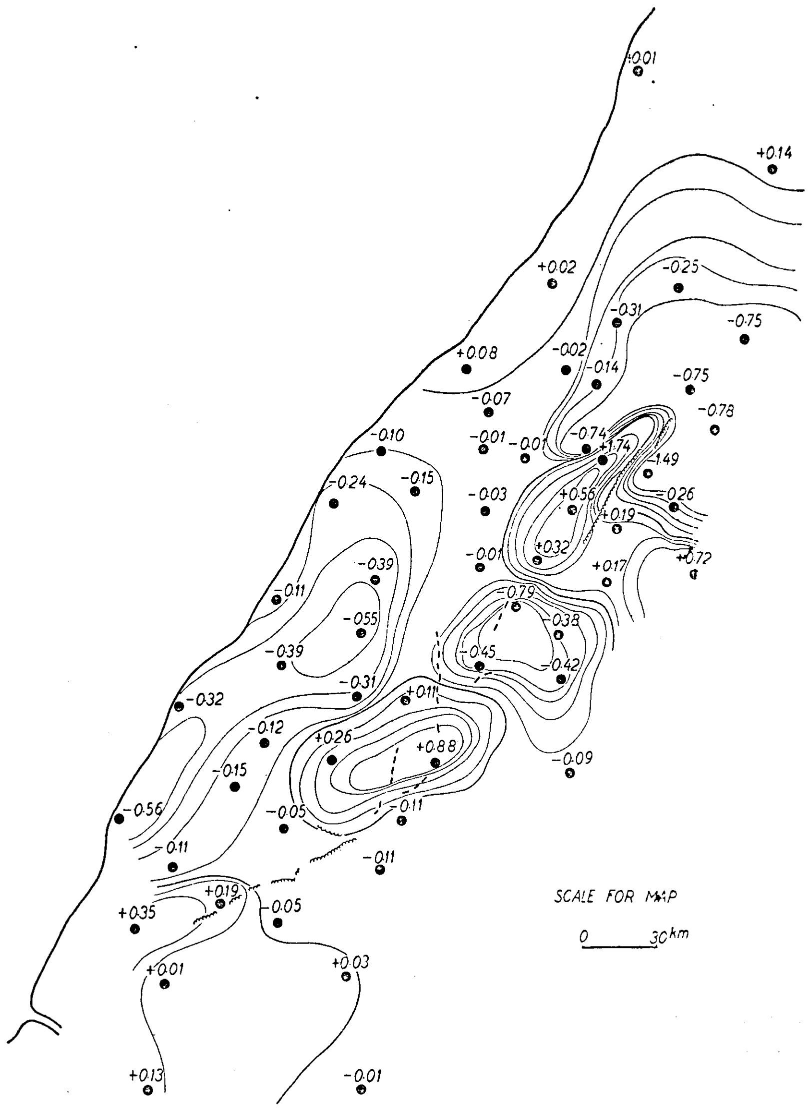

Fig. 6. Distribution of vertical displacements.

relatively elevated. It may be added that most of the epicentres of the after-shocks were found to be in this elevated and compressed zone.

Although the southern part of this compressed zone was not elevated appreciably, many landslides occurred there in association with the destructive earthquake.

To study such relation in greater detail, profiles of the horizontal divergence and those of the vertical earth movements along several lines crossing, perpendicularly, the line representing the Siko fault, were taken as shown in Figs. 7 a~d.

It will be seen from these figures that, in the northern part, as in Fig. 7 a~b, the horizontal divergence and the upward movements of the earth's crust are in positive correlation, whereas, in the southern part, as in Fig 7 c, these two quantities are in negative correlation.

This difference in correlation between the vertical earth movements and the horizontal divergence in the zone that includes the Siko fault may be regarded as indicating that, in the northern part, the after-shocks were frequent, while in the southern part, landslides were frequent, although the causal relation of these two phenomena and their corresponding correlation cannot easily be explained.

4. To ascertain the nature of the active faults that appeared at the time of the destructive earthquake, the distribution of horizontal displacements was studied.

The components of the horizontal displacements of the triangulation points, both parallel and perpendicular to the line representing the general trend of the Siko fault, were calculated, their distributions being shown in Figs. 8~9.

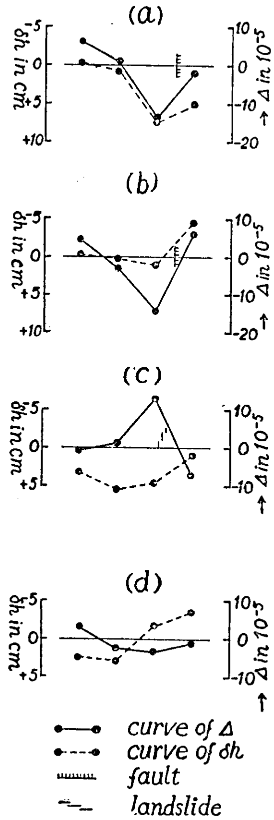

Fig. 7. δh and $\varDelta$ along the W—E sections.

As to the distribution of the parallel components of the horizontal displacements, nothing remarkable was noticed. The distribution of the perpendicular components, however, shows that the two parts of the earth's crust dissevered by the Siko fault will be seen to have moved as if the one compressed the other. As the result of such a crustal deformation, the western part of the earth's crust overthrusted the eastern part, as reported by Otuka.[5]

There are, however, several exceptions, in a number of triangulation points, the horizontal displacements deviated from such a general tendency as mentioned above, i. e. the points on the western side of the

5) Y. OTUKA, *Bull. Earthq. Res. Inst.*, Suppl. Vol. 3 (1936), 22~74. This fact was also referred to in the preceding report. *loc. cit.* 1).

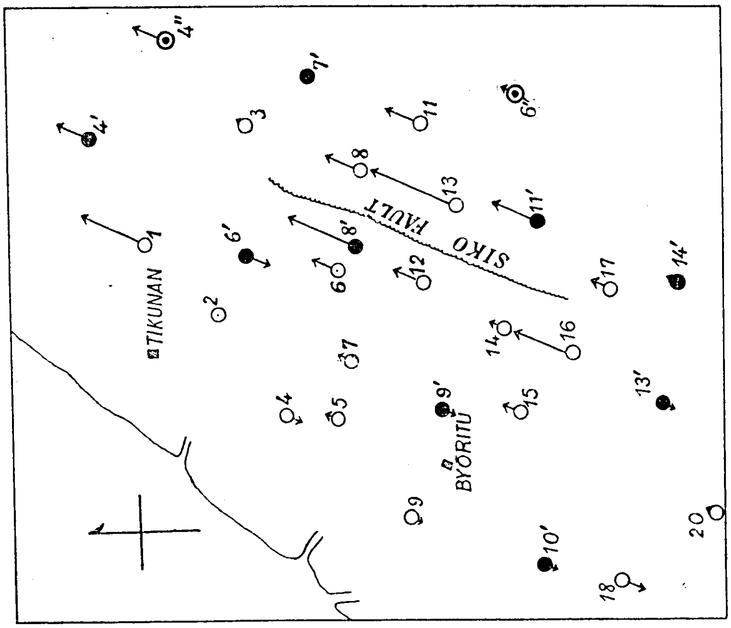

Fig. 8. Distribution of components of hor. displ. parallel to the Siko fault.

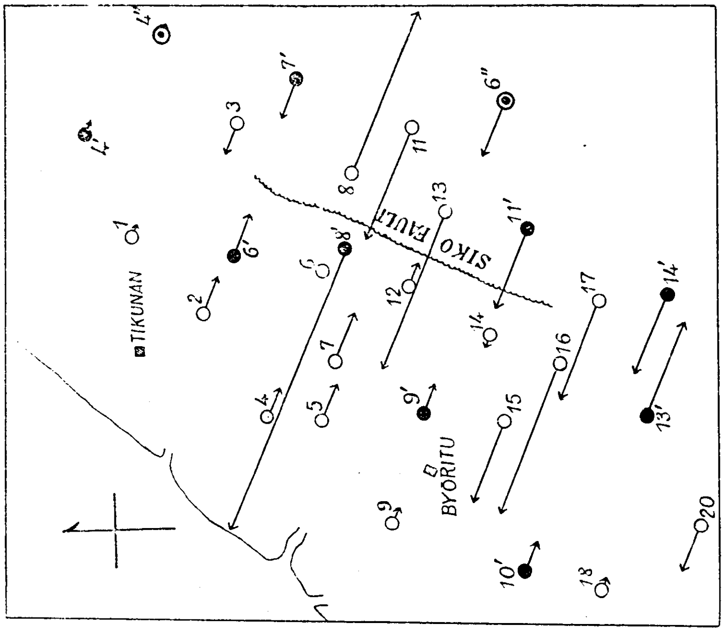

Fig. 9. Distribution of components of hor. displ. perpendicular to the Siko fault.

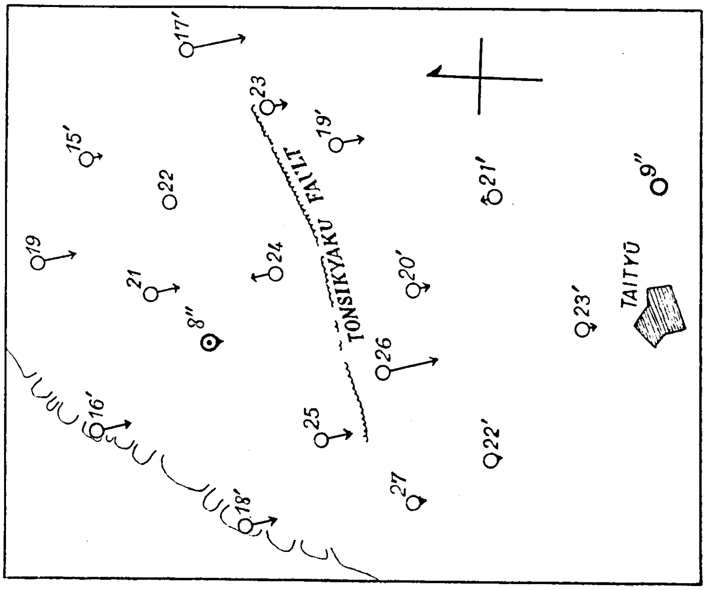

Fig. 11. Distribution of components of hor. displ. perpendicular to the Tonsikyaku fault.

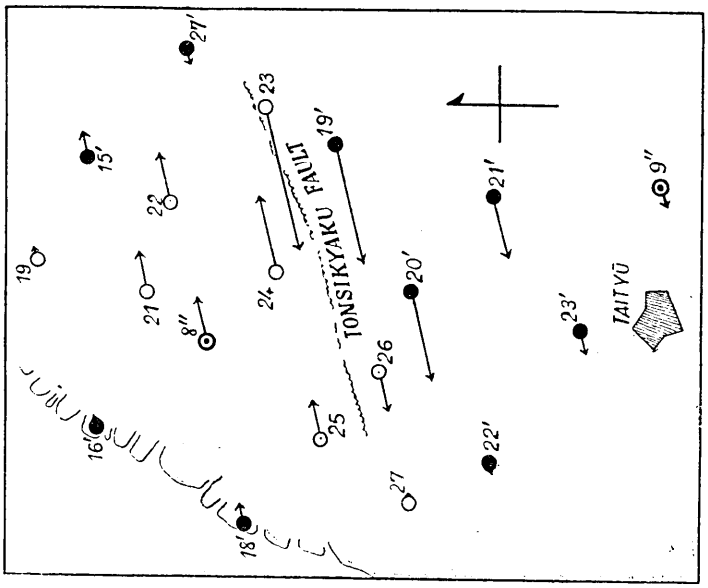

Fig. 10. Distribution of components of hor. displ. parallel to the Tonsikyaku fault.

Siko fault moved westward, while those on the eastern side moved westward, while those on the eastern side moved westward. For example, triangulation point 8, situated eastof the Siko fault, was displaced 0·95 m eastwards, while triangulation point 8′, situated west of the fault, was displaced 1·70 m westwards. In that region north of the apparent northern end of the Siko fault, triangulation points 1, 4′, 4″ were displaced northeastwards, i. e. approximately parallel to the direction of the line representing the general trend of the fault.

The triangulation points in the region where many landslides occurred, triangulation points 14′, 15, 16, 20 were displaced northwestward, although they are situated west of the estimated southward extension of the Siko fault, while, the displacement of triangulation point 13′ is directed southeast, which however is regarded as being on the east side of the Siko fault.

The distribution of parallel and perpendicular components of horizontal displacements of the triangulation points on both sides of the Tonsikyaku fault are shown in Figs. 10∼11.

In this case, the distribution of the perpendicular components does not show any marked characteristics, while that of the parallel components is distributed similarly to those observed in the Tango earthquake of 1927,[6] and the Idu earthquake of 1930,[7] i. e. the triangulation points situated north of the fault were displaced eastward and those in the southern part were displaced westward.

The general mode of distribution of the horizontal displacements of triangulation points in the region traversed by the Siko and the Tonsikyaku faults, agree well with the actual mode of dislocations observed along the active faults; that is to say, along the Siko fault, as already mentioned, the western part of the earth's crust overthrusted the eastern part, while along the Tonsikyaku fault, the shear-type of dislocation predominated, the vertical dislocation not being very marked.

5. It was reported[8] that a series of cracks are distributed in succession in a approximate line along the valley, from the north of Mt. Kwantôzan[9] northward to Rôkeiryû.[10] The distribution of these cracks is shown reproduced in Fig. 12.

As to the geophysical meaning of this series of cracks in connection with the 1935 earthquake, so far no one has attempted to explain it. It was supposed to be a mere topographic feature.

6) N. MIYABE, *Bull. Earthq. Res. Inst.*, **15** (1937), 654∼662.
7) S. YAMAGUTI, *Bull. Earthq. Res. Inst.*, **15** (1937), 899∼934.
8) *cf. Bull. Earthq. Res. Inst.*, Suppl. Vol. 3 (1936).
9) 關刀山. 10) 老雞隆.

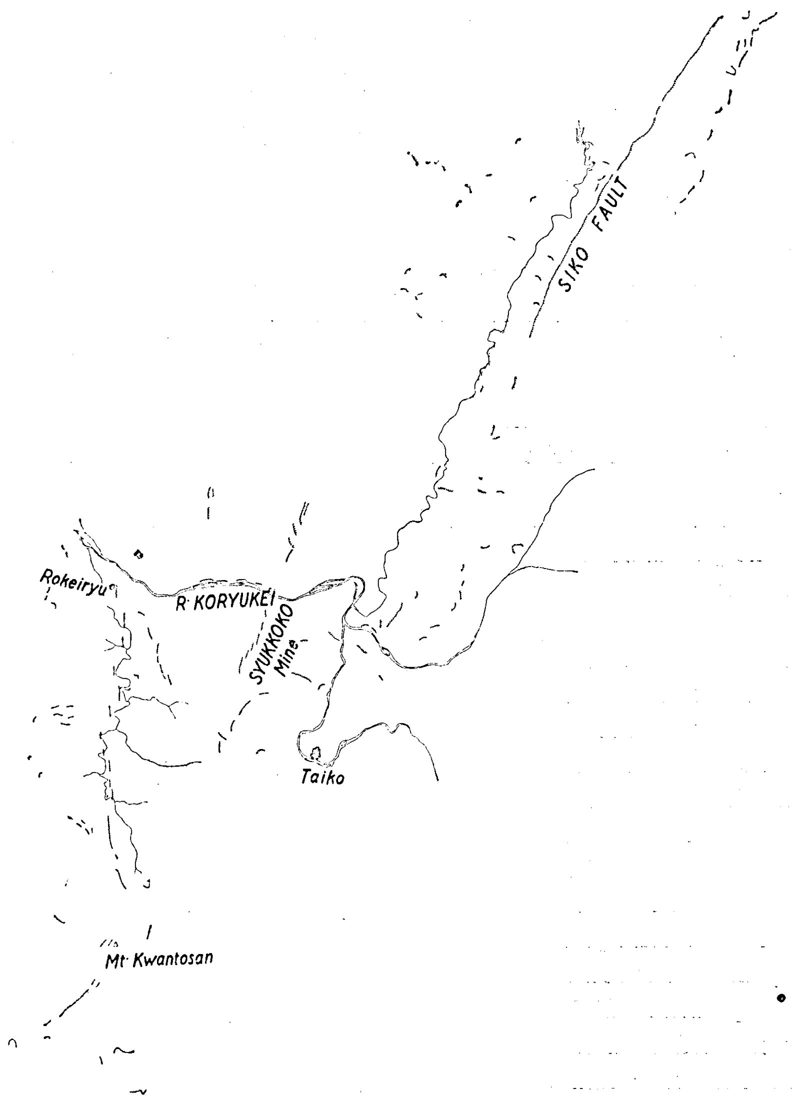

Fig. 12. Distribution of cracks.

In our present study, this series of succession of cracks was found to coincide approximately with the western boundary of the zone of marked horizontal compression, already referred to in the preceding paragraph. It is also notable that this zone of remarkable compression, situated west of the Siko fault, approximately coincides with the zone of the Syukkôkô anticline. In the Syukkôkô mine and neighbourhood, there are many traces of landslides and cracks that occurred at the time of the destructive 1935 earthquake.

The following is our explanation of the foregoing phenomena.

The zone of the Syukkôkô anticline suffered marked disturbance in association with the 1935 earthquake, especially in its northern part, where the earth's crust was elevated more or less. The result of this marked disturbance in the Siko fault on the eastern boundary; and the Kwantôzan-Rôkeiryû line on the western boundary of which we find a succession of cracks.

That part of the earth's between the Siko fault and the Kwantôzan-Rôkeiryû line of succession of cracks, together with their southward and northward extensions, very severely disturbed at the time of the 1935 earthquake.

6. The distribution of horizontal displacements of the triangulation points in the neighbourhood of the Tonsikyaku fault deserves further study.

The distribution of horizontal displacements of triangulation points in the neighbourhood of the Tonsikyaku fault is shown in Fig. 13. If we draw a pair of nodal lines (thick lines) in Fig. 13, intersecting with each other near Tonsikyaku we find that there is some sort of system in the directions of the horizontal displacements of triangulation points distributed in each quadrant divided by the nodal lines.

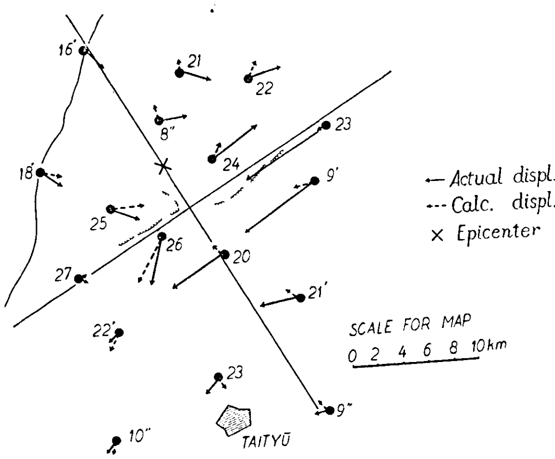

Fig. 13. Distribution of horizontal displacements in the neghbourhood of Tonsikyaku fault.

On the other hand, the directions of the horizontal components of the initial motions at various stations due to the destructive earthquake of April 21, 1935, reproduced in Table II,[11] are distributed systematically in the following manner.

The direction of the initial motion of the earthquake at Taihoku[12] was NE. Taihoku being situated in the 1st quadrant, as shown in Fig. 13, the direction of the initial motion of the earthquake agrees with the

11) Taken from Kensin-Zihō, 9 (1935), 3—9.
12) 臺北.

Table II.
Components of amplitudes of first motion of the 1935 earthquake.

station	N—S	E—W	U—D
Taityu	-210μ	-120μ	60μ
Arisan	−100	5	300
Kwarenkô	205	−412	− 27
Taihoku	N	E	11
Tainan	S	W	U
Taitô	− 36	23	77
Takao	1·9	0·5	—
Kôsyun	− 30	10	12

directions of the horizontal displacements of the triangulation points in the same quadrant and also near the point of intersection of the nodal lines.

The initial motion at Kwarenkô[13] was toward SW, so that its direction is approximately the same as those of the horizontal displacements of the triangulation points in the 4th quadrant, in which Kwarenkô is situated.

The directions of the initial motions of the earthquake that occurred at Taityû[14] and other stations situated in the southern part of Taiwan are south and southwest, the same as the directions of the horizontal displacements of triangulation points in the 3rd quadrant.

The coincidence in distribution of the directions of the horizontal displacements and that of the directions of the initial motions of the seismic waves observed at various stations has already been discussed by Ishimoto in connection with the mechanism of earthquakes, as also for the case of other earthquakes. According to Ishimato's theory,[15] the horizontal displacement at a point (r, θ) is expressed by

$$\frac{1}{4}\phi + \phi'$$

when the seismic waves originate from a quadrupple source, where ϕ and ϕ' are given, for simplest case, by

$$\phi = \frac{e^{iht}}{r} P_0,$$

and

$$\phi' = \frac{e^{iht}}{r} P_2(\cos\theta).$$

With the aid of the above expression, the horizontal displacement of a number of triangulation points were estimated as shown by the dotted arrows in Fig. 13. The magnitudes of the calculated displacements are obviously arbitrary. They have been adjusted so that one

13) 花蓮港. 14) 臺中.
15) M. ISHIMOTO, *Bull. Earthq. Res. Inst.*, **11** (1933), 254.

of the calculated displacements shall coincide in magnitude with the corresponding actual displacements. The discordance, as seen in Fig. 13, between the calculated and the actual displacements may be due partly to the assumption from which the actual displacements have been deduced, namely, that the displacements of two triangulation points situated far from the region disturbed by the earhquake are zero, and partly to the fact that the actual displacements consisted, as a rule, of acute movements caused by the crustal deformation associated with the earthquake and the cumulative movements that had been going on in the time interval between the old and new surveys.

It is also interesting that the point of intersection of the two nodal lines is situated very near the epicentre of the earthquake as determined by Kawasumi and Honma,[16] denoted by × in Fig. 13.

7. Lastly, the magnitude of the disturbance of the earth's crust in the region under consideration was studied.

First, we plotted a frequency curve of the triangular areas, the horizontal strains for each of which were calculated, assuming that the deformations in each of the triangular areas was uniform. In Fig. 14,

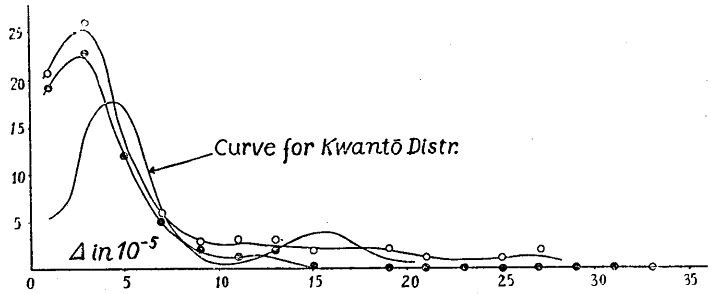

Fig. 14. Frequency of triangles plotted against Δ.

the frequency curve of the horizontal divergence thus plotted is shown by filled circles.

Second, the whole region under consideration was divided into a mesh of 5 km, and the mean values of certain strain components were calculated for each unit mesh, after which the frequency curves for the meshes were plotted against one of the strain components. As an example, the frequency curve of the divergence thus plotted is shown in Fig. 14 by the circles.

For comparison, a similar curve for the crustal deformations associated with the Kwanto earthquake of 1923[17] was plotted, as shown

16) H. KAWASUMI and S. HONMA, *Bull. Earthq. Res. Inst.*, Suppl. Vol. 3 (1936), 10~21.

17) N. MIYABE, *Bull. Earthq. Res. Inst.*, **11** (1933), 637~691.

in the same figure. The frequency maximum occur at $\Delta=4\times10^{-5}$, the second maximum does not appear in the frequency curve of divergence for the crustal deformation in Central Taiwan, whereas, in the case of crustal deformation in the Kwanto district, it occurs at $\Delta=6\times10^{-5}$. This however may be no more than an indication of the fact that the

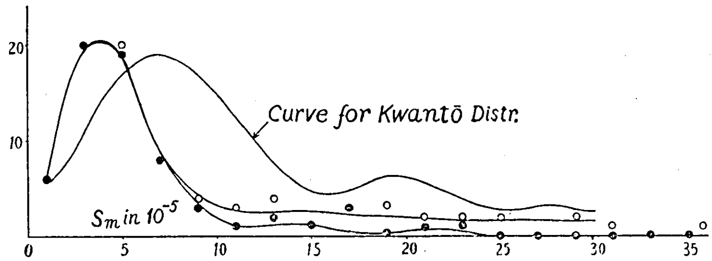

Fig. 15. Frequency of triangles plotted against S_m.

region of marked disturbance is limited to a narrow zone, as already mentioned.

The same thing was also noticed in the frequency curves of S_m, as shown in Fig. 15.

8. Summary. In the present paper, the writers studied the modes of crustal deformation that was associated with the destructive earthquake of April 21, 1935, that occurred in Central Taiwan (Formosa), by using the data of horizontal and vertical displacements of triangulation points. The following are the outstanding results of our study;

(i) A narrow zone of remarkable disturbance was found, extending in a N—S direction, and bounded by the Siko active fault on the east and by the Kwantôzan-Rôkeiryû line of succession of cracks on the west. This zone of remarkable disturbance approximately coincides with the zone of the Syukkôkô anticline.

(ii) The distribution of the horizontal displacements of triangulation points in the neighbourhood of the Tonsikyaku fault suggests its coincidence with the distribution of initial motions that began at the various stations from the earthquake. A pair of nodal lines, estimated from the distribution of the horizontal displacements, was found to coincide with those deduced from the distribution of initial motions that began at various stations, within, of course, the allowable limit of errors. The point of intersection of the two nodal lines lies very close to the epicentre of the earthquake.

42. 臺灣中部の地殼變形 第2報

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昭和10年4月の地震の際に災害を被つた臺灣中部地方の地殼變形に關しては，既にその概略を，該地域に在る一等三角點の移動並に水準點の高さの變化の資料に基いて研究し，之を第1報として報告した.

その後，同一地域内の二等及び三等三角點の水平移動並に高さの變化が測量されたので，本報告では，是等の資料に基き，前號より稍々詳細に地殼變形の模樣を調べた.

研究の結果の主要なる點を擧げれば，次の通りである.

(i) 紙湖斷層の西側に於いて，この斷層に沿ひ水平方向の變形の著しい地帶がある. 換言すれば，水平方向變形の著しい狹長なる地帶が南北に延びて居り，その東線の一部が紙湖斷層となつてゐる. 而してその西線の一部は，關刀山一老雞隆間に顯れた一連の割目列に一致する. 又，この變形地帶は，大體に於いて，所謂，出鑛坑の背斜軸を中心とする地帶に一致する.

(ii) 屯子脚斷層の方向を一つの節線とし，之と之に直角な節線とで4地域を分けるとその各地域における水平移動ヴエクトルの分布は，嘗て，石本博士が指摘したやうに，震源における適當な發震機巧から期待される初動の分布と稍々似てゐる. 而して，これ等の2節線の交點は河角博士等の決定したこの地震の震央の位置に非常に接近してゐる.