1. *On the Vertical Earth Movement in Kwantô Districts.*

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Introduction.

The secondary and tertiary triangulations in Kwantô Districts have been carried out and now completed by the authorities of the Military Land Suvery Department.[1] From the result of these extensive surveys, the vertical displacements of the triangulation points are found which we may assume to have occurred during the time interval of 1889-1925. In the present paper, we tried, in the first place, to discuss the geographical distribution of these vertical displacements.[2] On the other hand, we have already made a preliminary investigation of the horizontal deformation of the earth's crust in the same districts,[3] referring to the result of the primary triangulation which had been completed by the same authorities. In the present paper, the relation between the horizontal divergence and the vertical earth movement will be discussed in the second place.

In the present investigation, however, we leave out the problem whether these displacements of triangulation points represent the true movement of the earth's crust in their neighbourhood or the movement more or less affected by the local disturbances such as the accidental displacements of the triangulation points etc., and simply assume that the displacements of the triangulation points are mainly due to the average crustal movement in their neighbourhood. Even if the components due to other local disturbance existed, their amounts may be more or less reduced by the process of smoothing the values of the vertical displacements. It may be also considered that those com-

1) *Bull. I. E. I. C.*, **11** (1930), No. 4.
2) An abstract is appeared in *Proc. Imp. Acad.*, **6** (1930), 405.
3) T. TERADA and N. MIYABE, *Proc. Imp. Acad.*, **6** (1930), 49.

ponents due to the local disturbances, if they exist, are the secondary effect resulting from some irregular local deformation of minor scale, i. e., of less extent than the primary block movement. These minor local disturbances are discussed as the distribution of D (the value that represents the grade of disturbance). It may also be remarked that these vertical displacements include both chronic and acute components, the acute components being the direct effect of the earthquake, as we have already remarked in the previous paper with regard to the horizontal displacements.

The Process of Smoothing.

To see the general mode of distribution of the vertical movement of the earth's crust, the values of the vertical displacements of the triangulation points are subjected to a process of smoothing which will be described as follows. For this purpose, the topographical maps in 1/50000 scale of Kwantô Districts are taken, and the area of every sheet of these maps are divided into 16 minor meshes of equal areas, so that an unit mesh has the area of $(\Delta\lambda = 15/4') \times (\Delta\varphi = 10/4')$. The values of vertical displacements of triangulation points which fall in a major mesh of the area of $(\Delta\lambda = 15/2') \times (\Delta\varphi = 10/2')$, that is, four adjacent minor meshes, are averaged. This process of smoothing is performed all over the districts where the triangulation points, with their vertical displacements measured, are distributed.

The number of triangulation points which fall in a major mesh is approximately the same for each mesh without much deviation, except for those which are located in the marginal region of the districts. The mean number of the triangulation points in a major mesh amounts to about 10, the triangulation points which are situated on the boundary of the two adjacent meshes being counted twice in both meshes. In the following table, the first column contains the number of triangulation points in a major mesh, the second column the number of the major meshes with the corresponding number of triangulation points therein included and the third column is the percentage of the number of major meshes corresponding to the various number of triangulation points.

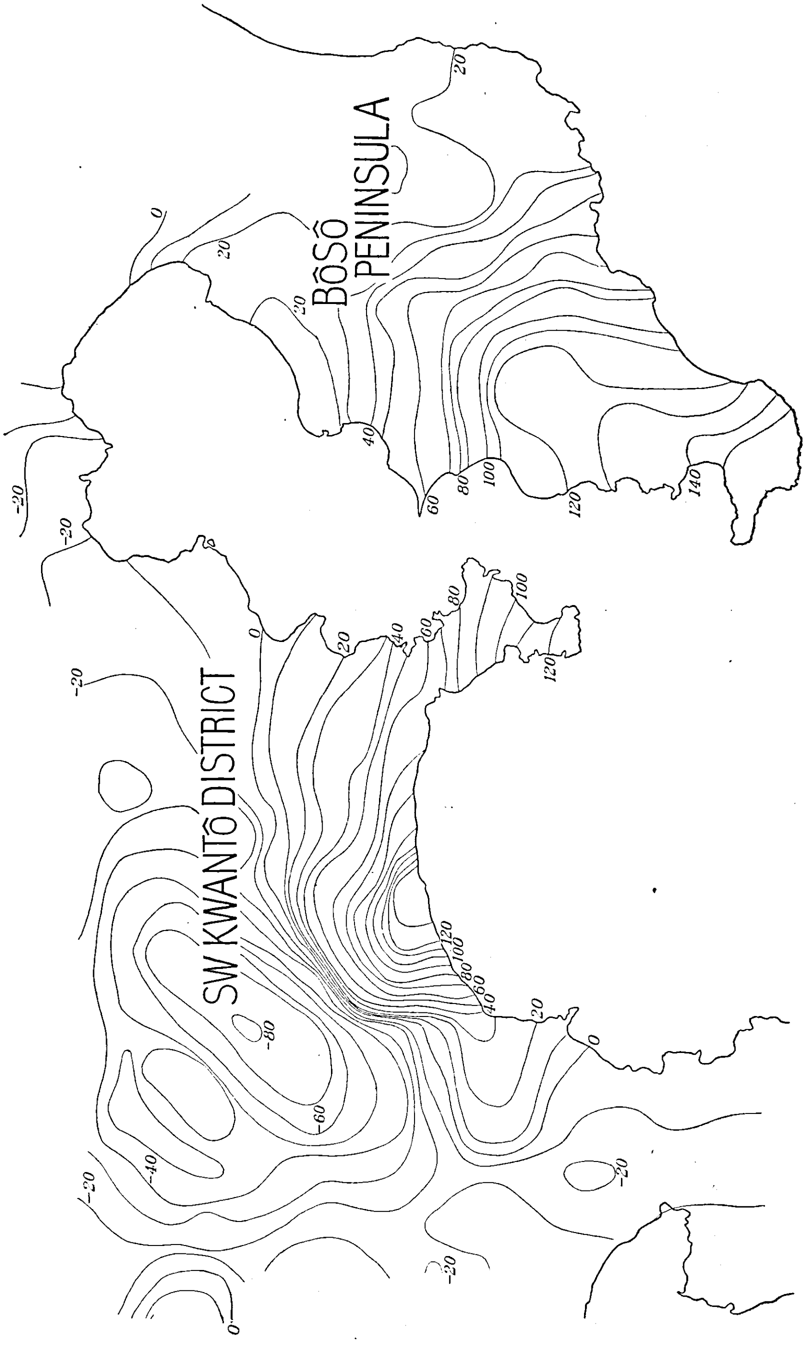

Fig. 1. Vertical Earth Movement in Kwantô Districts.

Table I.

The number of triangulation points per major mesh.	The number of major mesh.	%
2 – 5	29	9·8
6 – 7	44	14·9
8 – 9	61	20·6
10 – 11	87	29·5
12 – 13	52	17·6
14 – 15	22	7·5
	295	

The density of distribution of triangulation points is thus approximately uniform in this district, and the number of points in each major mesh is not much different from each other, as mentioned above and seen in the table. Hence, the mean values of vertical displacements obtained in the above may be regarded as equally weighted. Thus the equi-$\overline{\delta h}$ lines[4] of Fig. 1 are drawn, showing the general mode of distribution of the vertical earth movement in this district.

The Irregular Distribution of the Values of D and the Slope of the Vertical Movement.

First we consider the quantity

$$D = \overline{\left|\delta h - \overline{\delta h}\right|},$$

where — denotes the mean value, i.e., $\overline{\delta h}$ is the mean value of δh's (the vertical displacements of triangulation points) in a major mesh, and $|\ |$ is the usual notation for the absolute value.

The quantity D is determined by two factors. The value of D may turn out large when the general slope of vertical movement is very steep and when the values of δh have a wide range of irregular variation in the mesh. In our actual case, however, the values of mean slope of the vertical movement are never so large as the most values of D obtained. The fact that the relation between the slope and D is not expressed in a simple form, which will later be referred to, may also mean that the values of D are not determined by the mere geometrical effect of the slope.

The values of the slope of the vertical movement in various portions are obtained in the following way: circles with radii of 3000m. in actual scale are drawn having their centres at the net-points of the

4) Equi-$\overline{\delta h}$ lines are drawn with the interval of $\overline{\delta h}=10$cm.

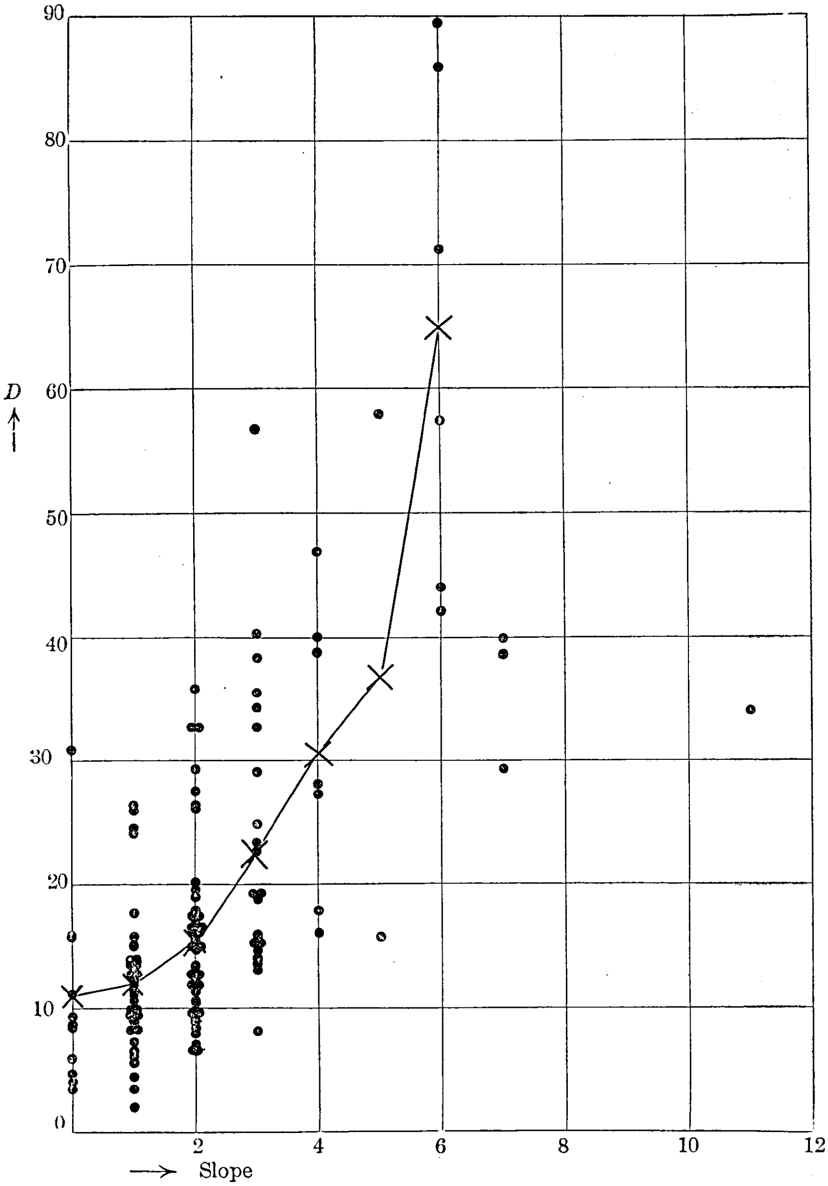

Fig. 2a. The Relation between D and the Slope of Vertical Displacements in SW. Kwantô District.

minor meshes, mentioned in the preceding chapter, and the number of contour lines of the map of Fig. 1 (for this purpose, contour lines are drawn with the interval of $\overline{\delta h} = 5$ cm.) crossing each circular area is counted to represent the slope in that very portion. To see the relation between D and and the slope, the values of D are plotted in ordinates, taking the slope of the corresponding portion in abscissae. The result is shown in Fig. 2a and b. Fig. 2a shows the relation between D and the slope in SW. Kwantô District and Fig. 2b is the similar relation in Bôsô Peninsula.

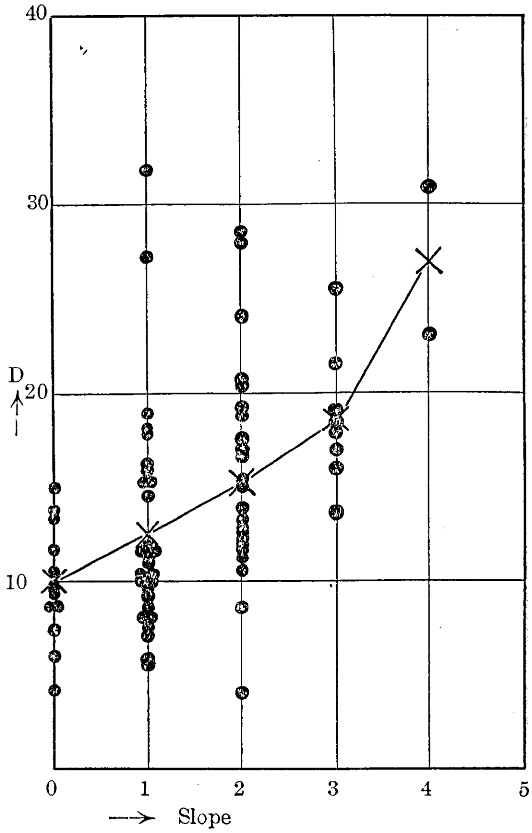

Fig. 2b. The Relation between D and the Slope of Vertical Displacements in Bôsô Peninsula.

The points showing the relation between D and the slope are distributed in more or less wide range in Fig. 2, and yet the mean values of D's for various slopes are somewhat systematically distributed which are shown in Fig. 2a, b, by the symbols × and the line connecting them. In Fig. 3, Pl. 1, showing the portions of relative maxima of D and those of the slope, we notice that those portions with two sorts of relative maxima are found to stand in some association. In other words, it may be suggested that some portions of the crust with large angle of slope of vertical movement frequently coincide with those portions with large local disturbance.

Geological Faults.

The deformation of the crust is seen, in the preceding chapter, concentrated in some finite portions. It may be suspected that the geological faults may also be associated in some manner with these portions with large D or slope. Under such considerations, the geological faults which are traced in the geological map compiled by Mr. S.

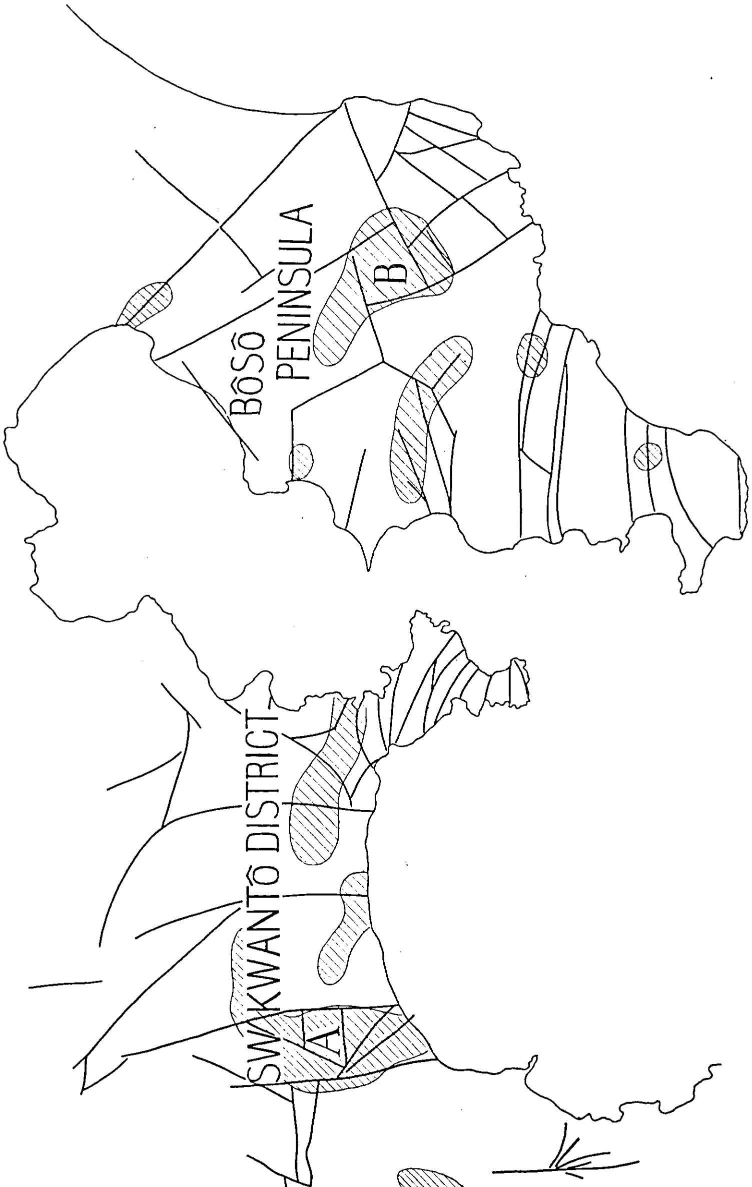

Fig. 4. The Distribution of Geological Faults.
Shaded Portions are those where the Values of *D* and the Slope are greater than the Surrounding Regions.
Full Lines are the Geological Faults, due to the Map compiled by Mr. S. Shimizu of Tôhoku University.

Shimizu of Tôhoku University, under Prof. Yabe's guidance, are reproduced in Fig. 4, which shows the regions where the values of D and the slope show relative maxima compared with the surrounding regions. At a glance on the figure, we notice the fact that there are some regions which is traversed by many geological faults and, at the same time, covered by the regions where the values of D show relative maxima. Such regions are found to the west of SW. Kwantô District marked by A and to the north of Bôsô Peninsula marked by B in Fig. 4.

So far as our present investigation is concerned, we cannot know whether every individual fault is significant for the process producing the present mode of the deformation of the earh's crust. From the result obtained, we can draw only a tentative conclusion that a swarm of faults, if it were permitted to use such a terminology, may be significant with regard to the crustal deformation.

Comparison with the Result of the Levelings.

Leveling surveys[5] were also carried out by the authorities of the Military Land Survey Department, along the routes covering the Kwantô Districts, some of them being revised for several times after the Great Kwantô Earthquake of 1923. Fig. 5 shows these leveling routes and the arrows in the figure mark the points where the slope of the vertical displacements along the routes is suddenly changed. The coincidence of these arrows with the regions of greater disturbance and steeper slopes are examined and several cases are found in which the arrows and the regions of greater D and slope are nearly coincident. Out of these cases of coincidence, two cases are remarkable in which these two sorts of discontinuities in δh, i. e., the discontinuity of δh in the triangulations and that found in the levelings, are fairly coincident. One of them is seen to the east of Odawara, marked by Arrow 1 in Fig. 5, where the western edge of Prof. Yamasaki's[6] Yurugi Land Block passes. The other is seen at the mouth of the Sagamigawa, Arrow 2, where a fault line is marked in the map compiled by Mr. Shimizu.

In some cases, however, the discontinuities in δh along the leveling routes and those obtained from the vertical displacements of triangulation points are not coincident. This discordance may partly be due

5) The results of the leveling surveys in this district are published by A. Imamura, *Publ. I. E. I. C.*, 25 (1930), etc.

6) N. YAMASAKI, *Bull. I. E. I. C.*, 100-B (1925).

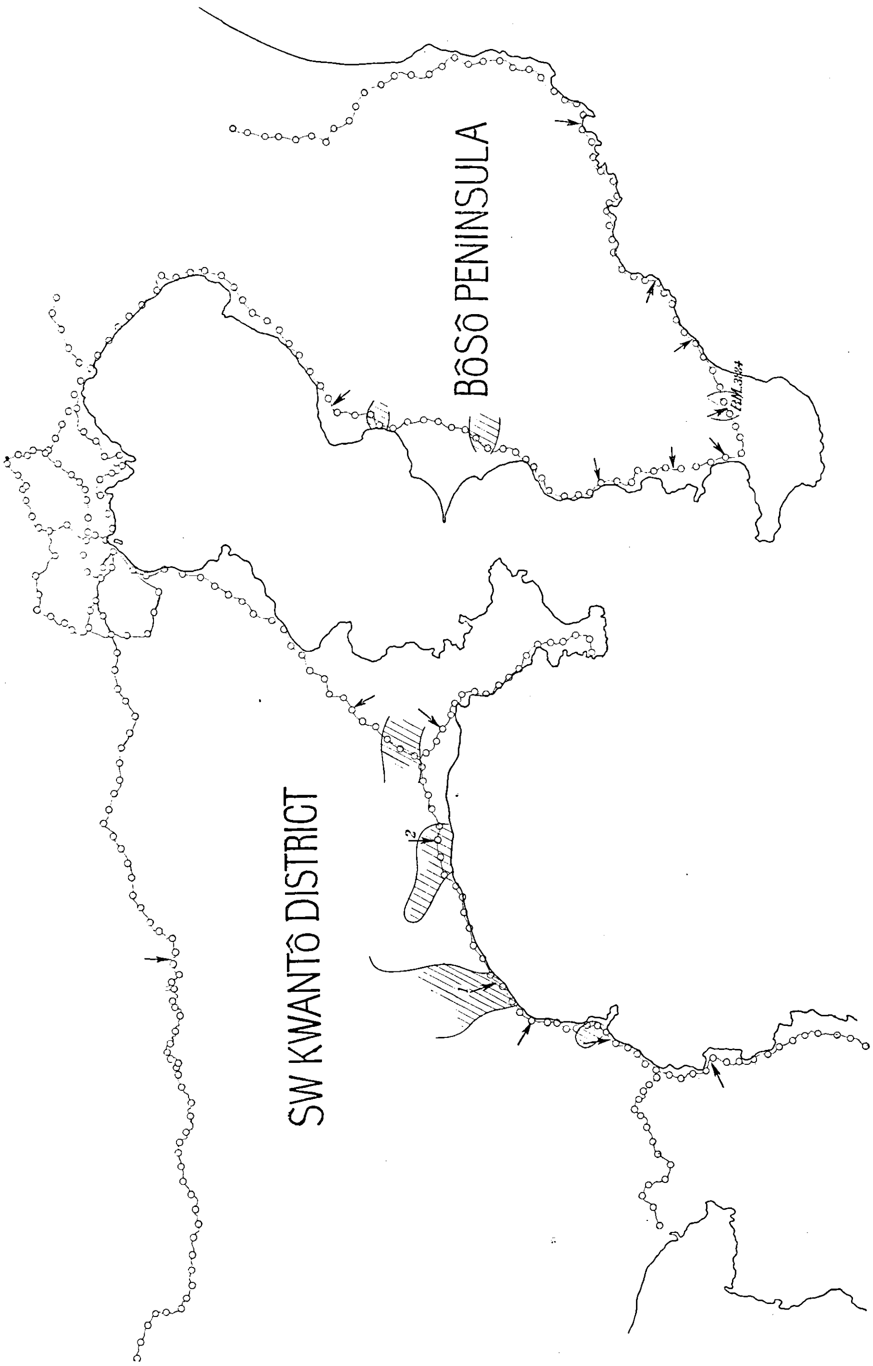

Fig. 5. Leveling Routes.
Arrows are Signs for the Points where the Slope of Vertical Displacements are suddenly changed.
Shaded Portions are the Regions where the Values of *D* and the Slope are greater than the Surrounding Regions.

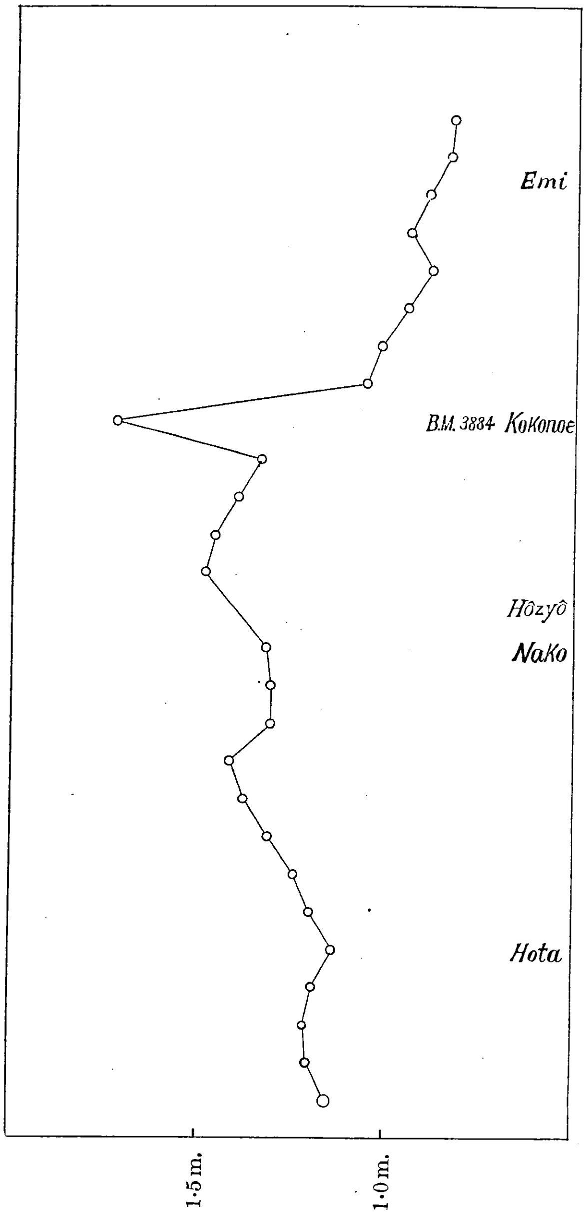

Fig. 6. The Abnormal Upheaval of B. M. 3884.

to the fact that the discontinuities deduced from the vertical displacements of triangulation points are those of the averaged movement of the surface of the earth, while, the discontinuities along the routes are due to the minor fluctuations in δh. Hence, in the portions where the crust was disturbed remarkably, the discontinuities found in the triangulation and those obtained from the levelings are found coincident as in the case of the western edge of Yurugi Land Block and that at the mouth of the Sagamigawa. It should be also remarked that a bench-mark near the SW. End of Bôsô Peninsula, B. M. 3884, is abnormally upheaved, as shown in Fig. 6, and this B. M. is situated in the region where the value of D is relatively greater than the surrounding regions.

We have another cause for the discordance between the two sorts of discontinuities mentioned above. It is a well known fact that the fluctuations in δh along the leveling routes are much affected by the configuration of the routes. Hence, the apparent discontinuities in δh along the routes do not always denote the discontinuities in crustal deformation.[7]

Distribution of Divergence, Rotation, Shear and Strain Ellipses.

From the data of horizontal displacements of primary triangulation points, we have calculated the areal divergence, rotation and shear, and also directions and magnitudes of principal axes of strain ellipses in various portions in Kwantô Districts. The distributions of these quantities are shown in Figs. 7–10.

As to the distributions of divergence and the principal axes of strain ellipses, we have already made a preliminary discussion in the paper above cited.[8]

Examining the distribution of rotation ζ, Fig. 8, we notice that a zonal region with counter-clockwise rotation extends from the mountainous region lying towards W. of Kwantô Plain to Bôsô Peninsula through the middle part of SW. Kwantô District. This zone lies inserted between northern and the southern regions with clockwise rotation, ζ of the northern region being of less magnitude.

On drawing the contour lines on the map showing the distribution of shear S, the signs are disregarded, their magnitudes only being taken into consideration. Examining the distribution of S, Fig. 9, it may be

7) This point will later be discussed in detail.

8) T. Terada and N. Miyabe, *loc. cit.* 3).

In the maps given in the previous paper cited, some errors were found which, though not so serious as to affect the general conclusion, are corrected and shown revised in Figs. 7 and 10 of the present paper.

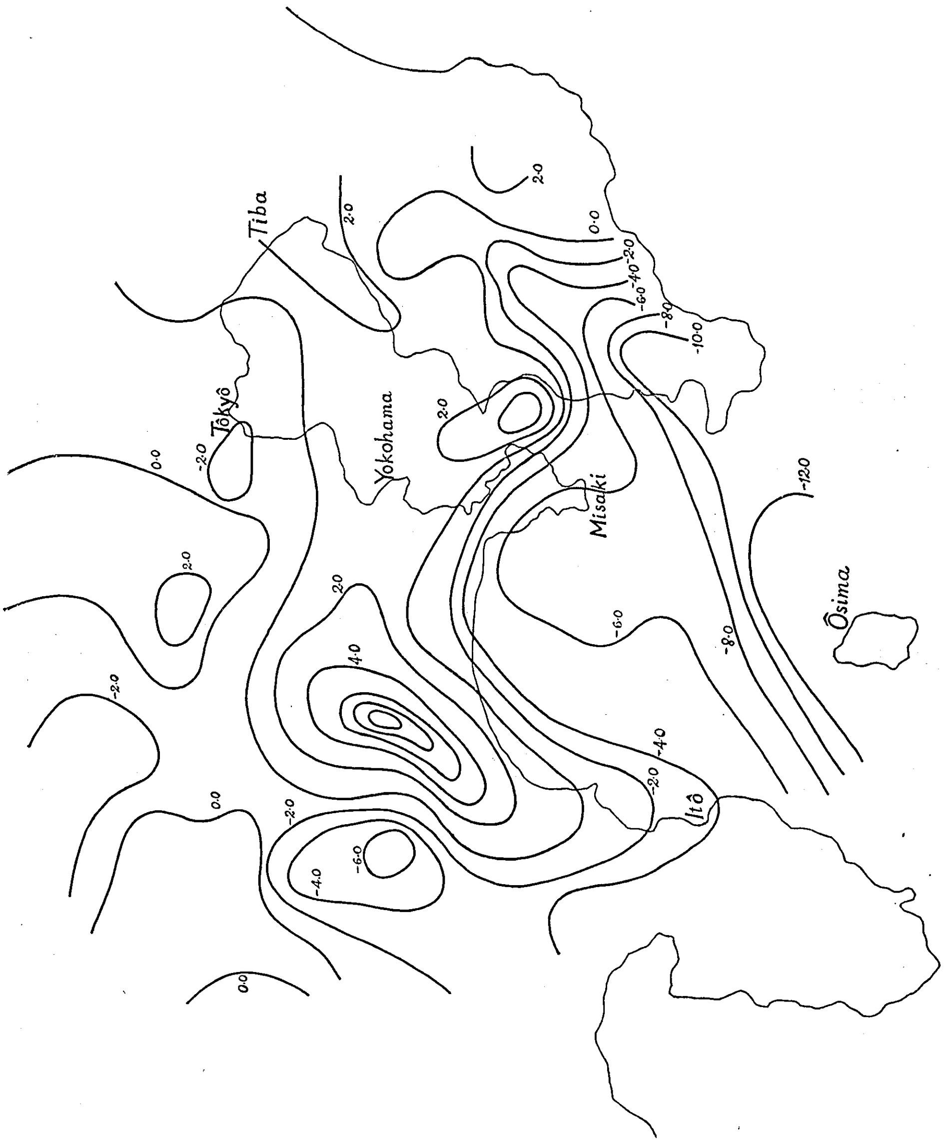

Fig. 7. Distribution of Divergence (10^{-5}).

remarked that the regions with the maximum values of S are found in the west of SW. Kwantô District and in Bôsô Peninsula. The region of maximum S in the west of SW. Kwantô District is approximately coincident with the region of maximum slope and consequently with that of D, which is mentioned in the preceding chapter. It is also seen

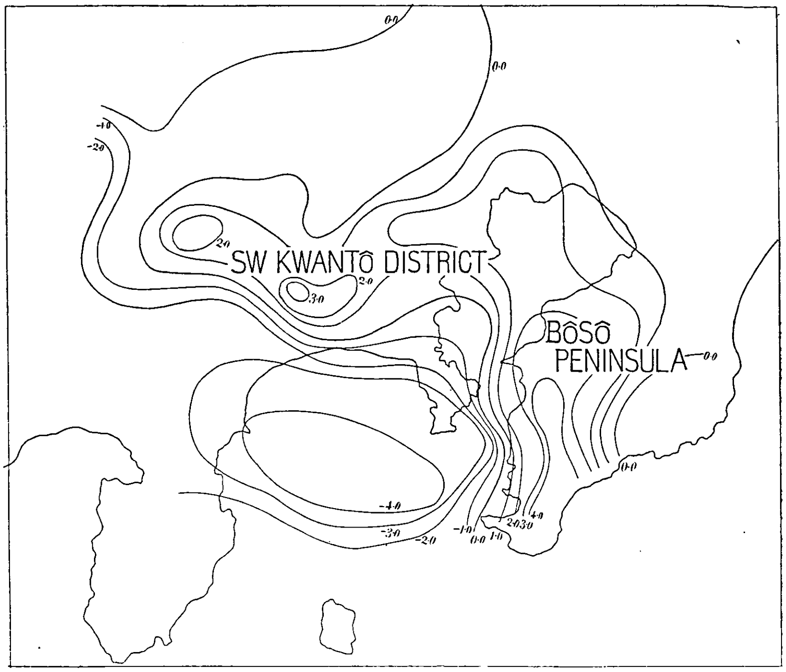

Fig. 8. Distribution of Rotations.
+···Region of Counter-Clockwise Rotation.
—···Region of Clockwise Rotation.

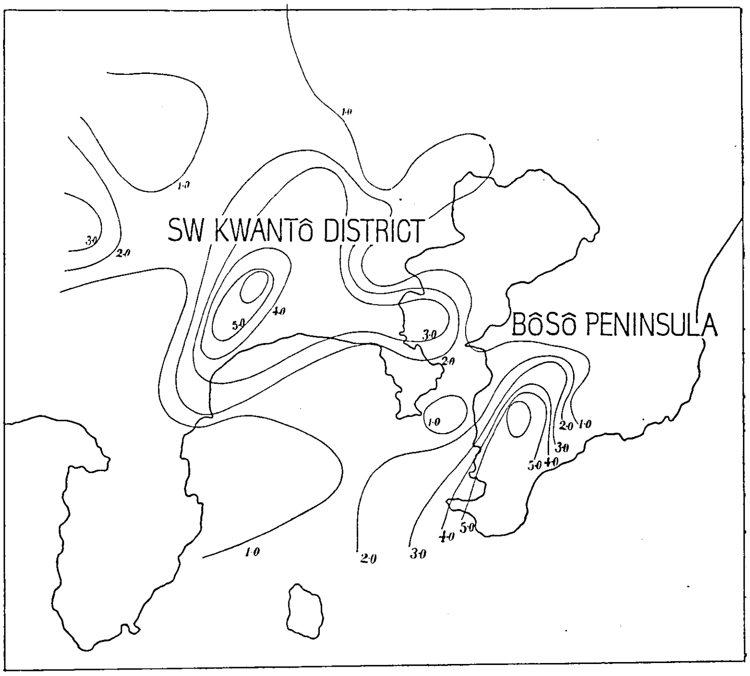

Fig. 9. Distribution of Shear *S*.

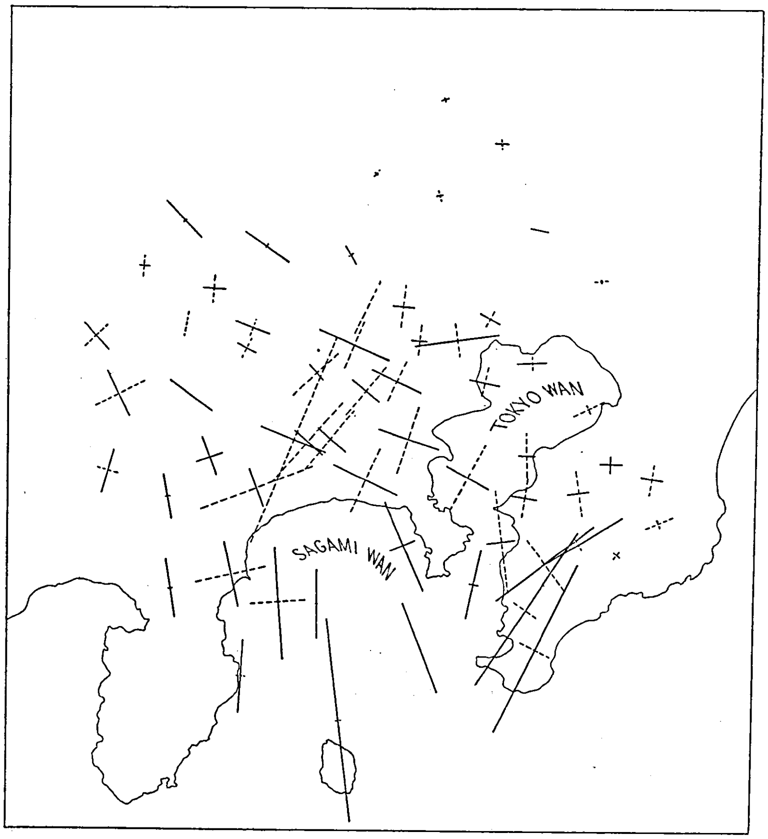

Fig. 10. Distribution of Principal Axes of Strain Ellipses.
Full Lines—Contraction, Broken Lines—Elongation.
Lengths of Axes denote Approximate Magnitudes.

to be coincident with the western edge of Prof. Yamasaki's Yurugi Land Block.

A region of relative maximum of S is extended in a zonal form over the middle part of Bôsô Peninsula from N. to S. Somewhat similar zonal distributions have been recognized in the distribution of the slope and that of D, but any close coincidence in position of these zones for the slope and D with the region for maximum S is not clearly seen, for the position of the latter cannot be determined with the same accuracy as the former. In this zonal region, however, conspicuous geological faults have not yet been found corresponding to this physical fault.[9]

9) The term "physical fault" is used for the discontinuities found from the data of the geodetic surveys.

The general mode of horizontal deformation of the earth's crust may be more easily appreciated, when the principal axes of elongation and contraction are connected respectively so as to build up the orthogonal trajectories of lines of elongation and contraction. Fig. 11

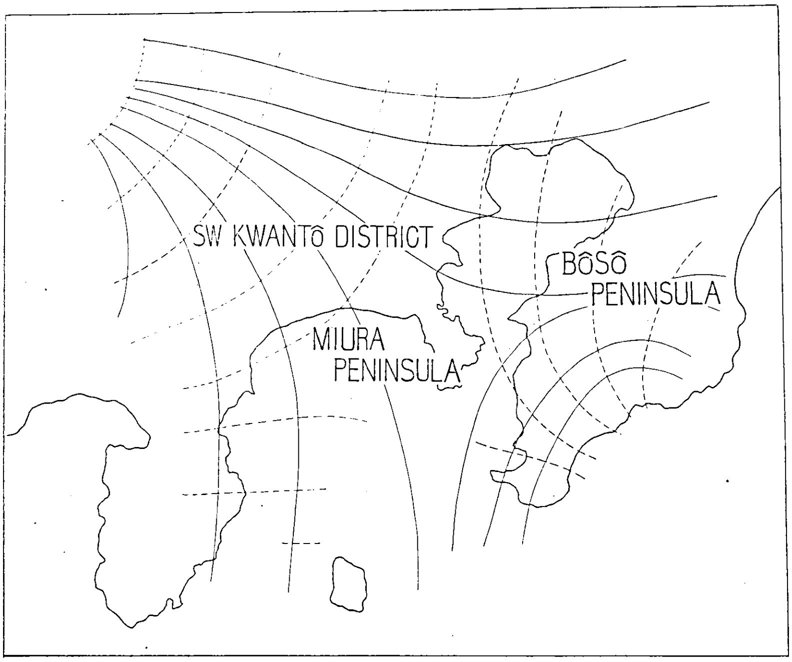

Fig. 11. Lines of Elongation (Broken Lines) and Lines of Contraction (Full Lines).

shows the general features of the system of the orthogonal trajectories of lines of elongation and contraction. We notice in that figure, that there is a region in the neighbourhood of Miura Peninsula which seems to have been instrumental in disturbing the uniform development of the deformation over the districts under consideration.

The Relation between the Vertical Movement and Horizontal Divergence of the Earth's Crust.[10)]

As we have mentioned, horizontal divergence Δ for each triangle, the vertices of which are the primary triangulation points, was calculated. The mean vertical movement $\overline{\delta h}$ for each triangle is now

10) An abstract is appeared in *Proc. Imp. Acad.*, 6 (1930), 409.

calculated from the data of vertical displacements of secondary and tertiary triangulation points which are situated in the corresponding triangle. The table below shows the numerical values of $\varDelta$ and $\overline{\delta h}$ for each triangle.

Table II.

No.	Group.	Primary triangulation points which are vertices of triangles.	Δ (10^{-5})	$\overline{\delta h}$ (cm.)
1	A	Misotai-Yama; Asitaka-Yama; Kamurigatake.	- 3·79	- 19·6
2		Kamurigatake; Sengen-Yama; Tanzawa-Yama.	6·06	35·4
3		Tanzawa-yama; Misotai-Yama; Kamurigatake.	- 6·06	- 56·0
4		Tanzawa-Yama; Misotai-Yama; Koganesawa-Yama.	- 4·14	- 46·7
7		Tanzawa-Yama; Simomizo; Segen-Yama.	4·73	27·8
8		Tanzawa-Yama; Tobinoo-Yama; Sengen-Yama.	10·05	40·9
9		Sengen-Yama; Tobinoo-Yama; Zama.	3·14	17·2
10		Sengen-Yama; Zama; Hutako-Yama.	0·14	46·9
11		Zama; Hutako-Yama; Kami-Numabe.	1·92	16·7
5	B	Tanzawa-Yama; Koganasawa-Yama; Takane.	- 0·10	- 39·8
6		Tanzawa-Yama; Takane; Simomizo.	2·86	- 42·3
12		Kami-Numabe; Renkôzi; Nagatuda.	- 0·33	- 20·7
13		Renkôzi; Takane; Simomizo.	- 1·69	- 21·2
14		Takane; Hongô; Renkôzi.	4·33	- 23·7
15		Renkôzi; Tokumaru; Hongô.	1·51	- 34·3
16		Renkôzi; Tokumaru; Hongô Kami-Numabe.	0·83	- 19·3
17		Tokumaru; Kami-Numabe; Tôkyô.	- 3·58	- 16·1
18		Tokumaru; Hôten; Tôkyô.	- 0·65	- 19·1
28		Renkôzi; Simomizo; Nagatuda.	1·62	- 27·3
19	C	Kuranami; Rokudizo; Ôtani.	- 2·91	23·3
20		Ôtani; Rokudizô; Itinomiya.	0·46	13·0
21		Ôtani; Itinomiya; Nonotuka.	2·97	16·0
22		Ôtani; Nonotuka; Mineoka.	0·02	64·0
23		Ôtani; Mineoka; Kanôsan.	- 5·82	102·2
24		Ôtani; Kanôsan; Kuranami.	1·38	57·0
25		Kanôsan; Nokogiri-Yama; Mineoka.	- 4·07	126·6
26		Nokogiri-Yama; Mineoka; Bôtaisan.	-10·21	129·6
27		Mineoka; Bôtaisan; Ôkawa.	-10·10	127·8

In Fig. 12, the relation between $\varDelta$ and $\overline{\delta h}$ is plotted, taking the values of $\varDelta$ in ordinates and those of $\overline{\delta h}$ in abscissae. Fig. 13 shows the location of the triangles, the vertices of which are the primary triangulation points. The geographical positions of the triangles represented by the sets of values of $\varDelta$ and $\overline{\delta h}$ in Fig. 12 may be found by identifying the numbers of the points in Fig. 12 and those of triangles in

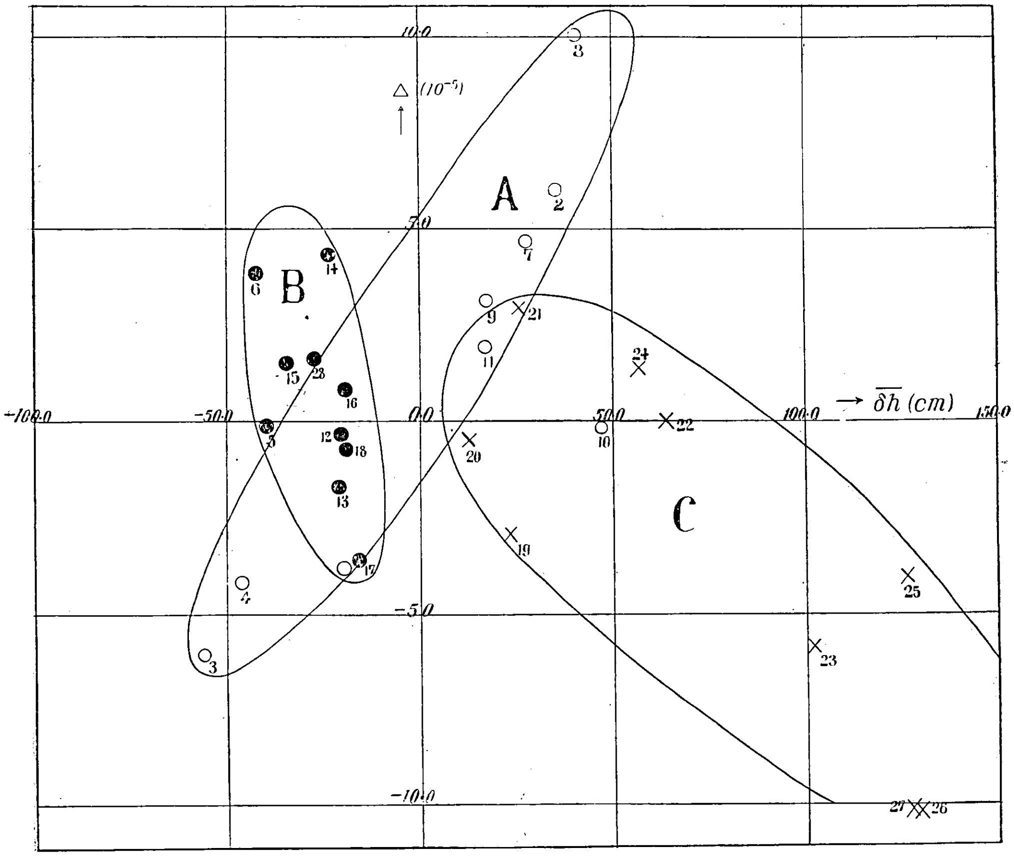

Fig. 12. The Relation between Δ and $\overline{\delta h}$.
○··· for Group A
●··· " " B
×··· " " C

Fig. 13. These plotted points in Fig. 12 may be classified into three groups, A, B and C. The triangles corresponding to the points belonging to Group A are in the southern part and those belonging to Group B are in the northern part of SW. Kwantô District. The triangles corresponding to the points belonging to Group C are situated in Bôsô Peninsula.

For the relation between Δ and $\overline{\delta h}$, we will tentatively assume an approximate linear one:

$$\Delta = \alpha + \beta\overline{\delta h},$$

where α and β are constants.

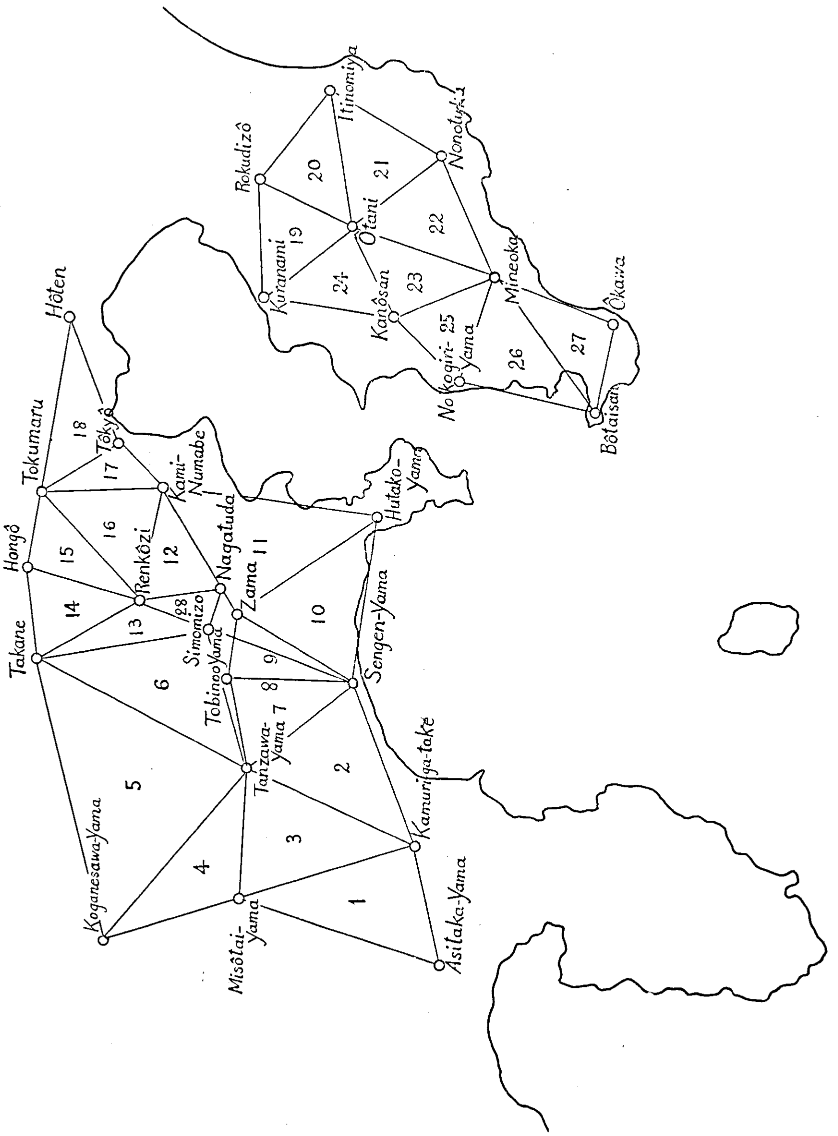

Fig. 13. Primary Triangulation Nets.
(Geographical Distribution of Triangles.)

First we consider the groups A and C. In Group A, the constant β of the above equation is positive, while, in Group C, it is negative. For these simplified relations represented by straight lines which may be drawn as major axes of elliptic areas in which the points for corrresponding groups are distributed, two different processes of deformation may be suggested. The one is such that the principal deformation is a flexure and the horizontal deformation occurs in such a way that the region of upheaval is forced to diverge and that of the depression is forced to to converge. Thus the relation of Group A may be produced. In the case of the deformation of Sakurazima, as we have investigated,[11] this relation is shown more or less remarkably. The other process of deformation is such that the principal deformation consists in the horizontal contraction and the vertical movement. In this case, however, the vertical deformation is possible either in upward or in downward directions. By this mode of deformation, for which the vertical deformation results in an upward movement, the relation for Group C, that is, the deformation in Bôsô Peninsula, may be produced.

The relation between Δ and $\overline{\delta h}$ in Group B, that is the deformation of the crust in the northern part of SW. Kwantô District may be mainly due to the secondary effect of the deformation in the southern part. The vertical movement in that region is comparatively smaller and not much different from each other, while Δ are varied widely. Moreover, there is an exceptional case, i. e., the relation between Δ and $\overline{\delta h}$ of the triangle No. 10, in which the value of Δ is much less than what will be calculated from the value of $\overline{\delta h}$ through the equation. This fact will be explained by the assumption that there might be some disturbance preventing the development of the horizontal deformation in this region.

Summary and Conclusion.

In the preceding pages, we have dealt with the vertical movement and its relation with the horizontal deformation of the earth's crust in Kwantô Districts. The results are summarized as follows:

1. Vertical displacements of triangulation points are smoothed so as to see the general mode of the vertical earth movement in this district, from which the mean slope of the vertical displacements is calculated in various places.

11) T. Terada and N. Miyabe, *Proc. Imp. Acad.*, 5 (1929), 322.

2. The quantity $D = \overline{|\delta h - \overline{\delta h}|}$ is calculated for each major mesh. The distribution of this quantity is compared with that of the slope and the coincidence of these two sorts of distributions is discussed.

3. The geological faults are traced and several regions of relative maxima of D and the slope are found to be coincident with those where the geological faults are more densely located.

4. In comparing the distribution of horizontal deformation with that of the vertical one, some regions with maximum horizontal shear are found in the regions of maximum values of D and the slope.

5. The relation between Δ (horizontal divergence) and mean vertical displacement $\overline{\delta h}$ is plotted and two different processes of deformation are suggested to serve for the explanation of the simplified relation between Δ and $\overline{\delta h}$.

In conclusion, the writer wishes to express his sincere thanks to Professor Torahiko Terada for his kind advices and guidance. The writer's thanks are also due to the authorities of the Military Land Survey Department for placing the valuable data at the writer's disposal.

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1. 關東地方に於ける地殼の垂直變動に就て

地震研究所 宮 部 直 巳

1923 年の關東地震の後に行はれた三角測量により、關東地方西南部及び房總半島を含む地域に在る二三等三角點の垂直移動が明かにされた。是等の資料により、筆者は、寺田教授指導の下に、この地方の地殼の垂直變動の模様を調べてみた。

茲に、是等の垂直移動量は、前回の測量との比較によつて算出されたもので、1889–1923 の間に起つた移動であることを考へねばならない。其故この移動量の中には、永年の間の除々なる移動によるものと、地震による急激なる變動によるものとを含む筈である。其等の二つの別々な性質の移動を分析することは困難であるから、此には、その全移動量を其儘取扱つた。

先づ地殼の垂直變動の模様を見るために、全面積を適當な網目に分ち、各網目内にある三角點の垂直移動量を平均してその網目に相當する面積の部分の垂直移動をあらはす様にした。かくして第一圖が得られたのである。この圖から各網目内での $D=\overline{|\delta h-\overline{\delta h}|}$ なる量所謂「もめ方」を表はす量、及びそれに相當する場所での傾斜を算出することが出來る。是等の量、即ち D 及び傾斜に就ては、それ等の値の極大値を持つ地域が接近してゐるといふことが知られた。

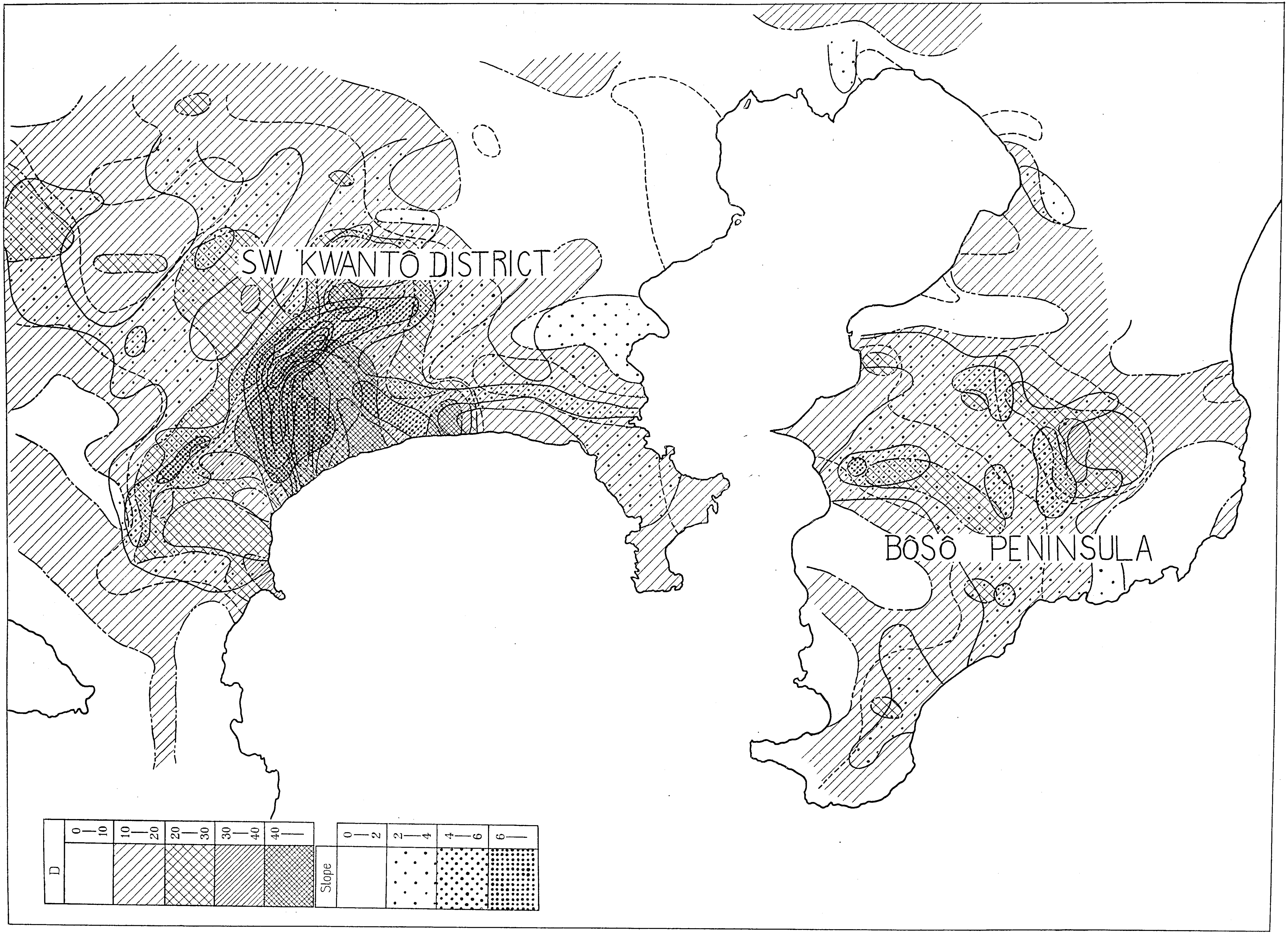

Fig. 3. Distribution of *D* and Slope of Vertical Displacements.

（震研彙報、第九號、圖版、宮部）

是等の D 又は傾斜が周圍に比較して大なる地域は、一つ一つの地質學的斷層とは必ずしも一致しないが、地質圖上で多くの斷層の過つてゐる地域とは略々一致する。

水準測量の結果と比較してみると、D. 及び傾斜の大なる地域と、水準線路に沿ふ水準變化量の不連續點とが略一致する場合も多いが、一致しない場合もある。

吾々は既にこの地方に於ける水平方向の地殼の變形を、一等三角點の水平移動量から計算したことがあるが、今その Horizontal Divergence $\varDelta$ と、三角點の垂直移動によつて代表される地殼の垂直變動量 $\overline{\delta h}$ との間には、近以的に簡單な關係が求められる。その關係を假に

$$\varDelta = \alpha + \beta\,\overline{\delta h}$$

とすると、α, β, は變形の仕方の相違による恆數である。即ち、關東西南部では β は正の値をとり房總半島では負の値をとる。この簡單な關係に相應して二つの地殼變形の仕方が考へられる。その一は、β が正、即ち、關東西南部の場合に適應するもので、主なる變形は flexure 的のものであつて上昇した地域は擴がり、下降した地域は縮む樣になる。その二は、β が負なる場合、即ち、房總半島の場合で、それは、水平方向の變形が contraction として起り、垂直方向の變形は（上及び下の二つの向に可能であるが、β が負なるために）上昇となる。

斯かる變形の仕方はこれまでに得られた結果の關する範圍內では至當の樣に思はれる。
