18. *Blocks in the Earth's Crust and their Movements. Part I.*[1]

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In Kwantô, Tango and other districts, where the leveling or triangulation surveys were carried out more than twice in the same districts, the vertical displacements of bench-marks or triangulation points are generally found which may be considered to have occurred during the time interval of the two successive surveys.

In the preceding paper,[2] the present writer pointed out that the apparent discontinuities in the vertical displacements of bench-marks are due partly to the configuration of the leveling routes. In the present paper, the writer introduced a method to analyse the data of vertical displacements of bench-marks, which might not be affected by the configuration of the leveling routes. Then he investigated block movements of the earth's crust referring to the data of vertical displacements of triangulation points in Bôsô Peninsula.

1. A Method for determining Blocks.

When vertical displacements of bench-marks or triangulation points are given, there may be a number of methods for determining the extent and form of each constituent block and also for investigating its movement. The present writer employed a method described as follows.

Taking pairs of triangulation points, we measure the distance s and the difference of vertical displacements δh between the two triangulation points, together with the azimuth θ of the direction of the line connecting

1) An abstract of the present paper was already appeared in *Proc. Imp. Acad.*, 7 (1931), 150.

2) N. MIYABE, *Bull. E. R. I.*, 9 (1931), 1.

the same pair of triangulation points, with reference to some definite direction, for instance, N. δh is divided by s, the distance between the two triangulation points, and the quotient is put equal to $\tan\phi$, where ϕ denotes the angle of inclination of the line connecting the corresponding pair of the triangulation points.

When a number of triangulation points are situated on the same block, θ's and $\tan\phi$'s measured between every pair of these triangulation points are connected by a relation expressed by an equation

$$\tan\phi = \tan\phi_m \cos(\theta - \theta_m), \tag{1}$$

where ϕ_m and θ_m denote the magnitude and the direction of the tilting of the block, respectively.

Conversely, if a number of triangulation points are such that the measured $\tan\phi$'s and θ's between every pair of them are connected with the relation (1), they are regarded as situated on a single block, ϕ_m and θ_m of which being estimated on the θ-$\tan\phi$ diagramme.

The relation (1), however, holds exactly right when the surface of the block is horizontal before its movement. If the surface of the block is inclined, or, two triangulation points of a pair are situated at portions of different heights, the slope may be expected to affect the value of $\tan\phi$ to some extent. To investigate the effect of the topographical slope, we consider two points A and B situated at different heights (Fig. 1). After a block-movement, B comes to B' relative to A. Let the height-difference

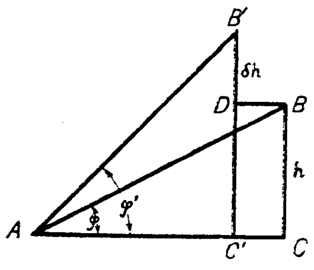

Fig. 1.

measured between A and B and that measured A and B' be h and $h+\delta h$ respectively, and AC be s, then we have

$$\tan\phi = \delta h/s = B'D/AC = (B'C' - DC')/AC = (B'C' - BC)/AC,$$
$$B'C' = AB'\sin\varphi', \qquad BC = AB\sin\varphi,$$
$$AC = AB\cos\varphi, \qquad AB' = AB.$$

Therefore, $\tan\phi = (\sin\varphi' - \sin\varphi)/\cos\varphi.$

Put $\varphi' = \varphi + \varDelta\varphi = \varphi + \phi,$

and we get $\sin\varphi' = \sin(\varphi+\phi) = \sin\varphi\cos\phi + \cos\varphi\sin\phi.$

Now ϕ is small enough for expanding $\cos\phi$ and $\sin\phi$ in terms of ϕ. Hence, we have for the approximation of second order

$$\tan\phi = \frac{\sin\varphi\,(1-\phi^2/2) + \phi\cos\varphi - \sin\varphi}{\cos\varphi}$$
$$= \phi - \phi^2/2\tan\varphi, \qquad (\tan\varphi = BC/AC = h/s)$$

where $-\phi^2/2\tan\varphi$ is a term of correction due to the topographical slope between the two points A and B. The value of the term of correction tends to be infinite, when φ approaches to $\frac{\pi}{2}$. Therefore, the correction due to the slope may not be disregarded when the topographical slope, φ, of the surface of the block is very near to $\frac{\pi}{2}$. But, in most cases, at least in our present case, magnitudes of φ's rarely exceed $\frac{\pi}{4}$. Hence, the correction due to the topographical slope, φ, may be disregarded in our present case.

2. Blocks in Bôsô Peninsula and their Movements.

The above method for determining the form and extent of each constituent block, together with the magnitude and direction of its tilting, was applied to analyse the data of vertical displacements of triangulation points in Bôsô Peninsula. Distances and directions, with reference to N., of lines connecting different pairs of triangulation points are measured on the topographical maps of the scale of 1/50000. Fig. 2 shows the block structure and tilting of each constituent block in Bôsô Peninsula obtained. Lengths and directions of arrows in the figure denote the magnitudes and directions of tiltings of constituent blocks. Dotted lines are probable boundaries of the groups of triangulation points which are regarded as

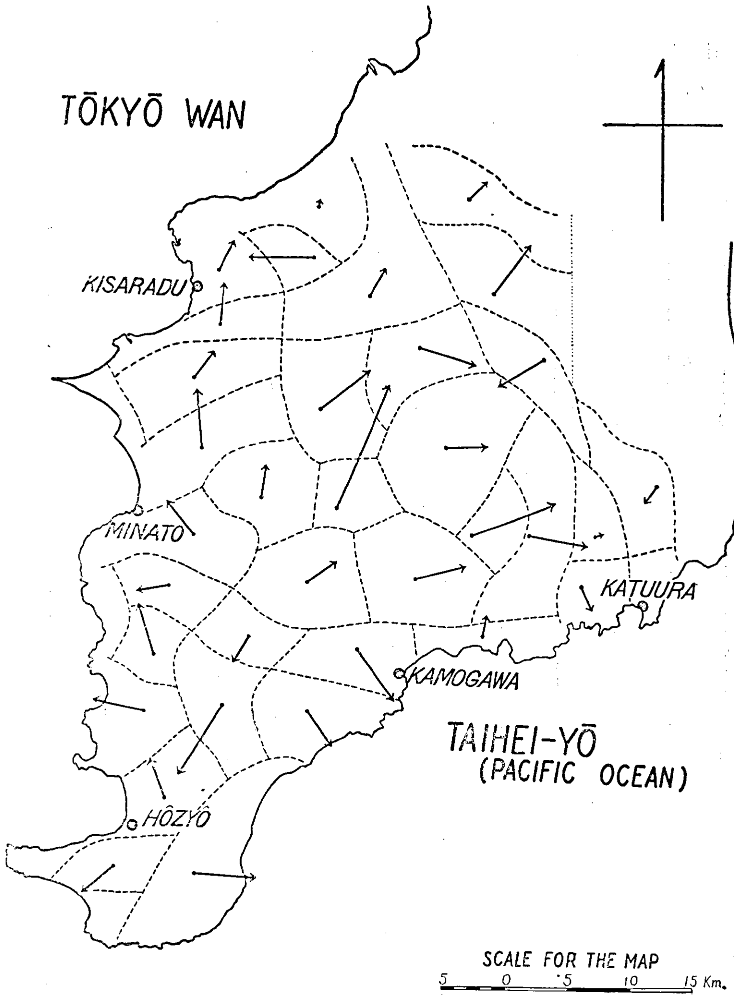

Fig. 2. Blocks and their Tiltings in Bôsô Peninsula.
(The Magnitudes and Directions of the Arrows correspond to those of Tiltings of the Blocks.)

situated on respective blocks. The relation (1) holds in each group of triangulation points or in each constituent block, as shown in Figs. 3, 4 and 5, which correspond to Blocks V, XIX and XXXIII respectively. In these figures, ○'s are the marks for the triangulation points which are regarded as situated on the respective blocks, the tiltings of which are represented by the curves drawn with thick full lines, while, ●'s are the marks for the triangulation points which are not on the same blocks as represented by the curves and the marks ○'s.

Examining the geographical distribution of the directions of tiltings of these blocks, we notice several groups of blocks, in each of which the directions of tiltings of the constituent blocks are approximately the same; for instance, a group of Blocks VIII (107°), XIX (89°), XXI (100°),

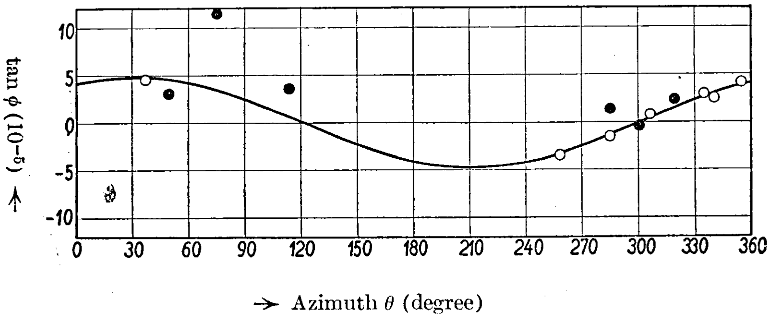

Fig. 3. (Block V).

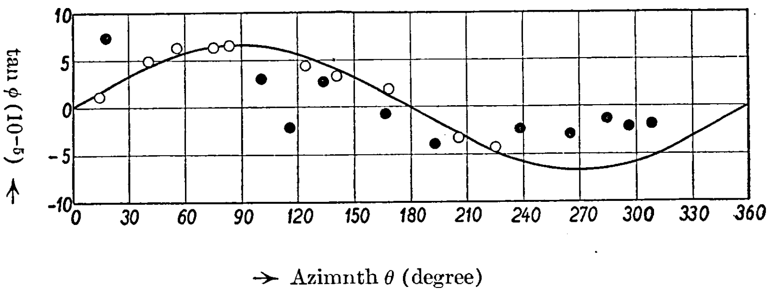

Fig. 4. (Block XIX).

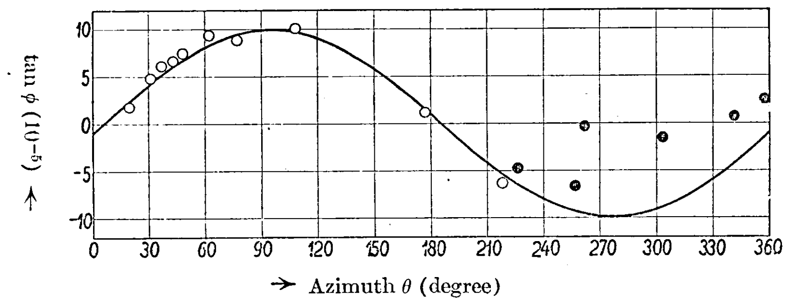

Fig. 5. (Block XXXIII).

XXII (73°), XXV (70°) and XXVI (76°) and another group of Blocks V (31°), VI (46°), VII (38°), IX (52°), XVII (55°) and XVIII (23°). The numerical figures in brackets are the values of θ_m's of the blocks. In several other cases, however, the directions of tiltings of adjacent blocks are remarkably different; for instance, the directions of tiltings of Blocks VIII (107°), XIX (89°), XXI (100°) and XXII (73°) are much different from those of Blocks XX (240°), XXIII (215°), and the directions of tiltings of Blocks XVII (55°) and XXVI (76°) are much different from those of Blocks XIV (261°), XVI (211°.5) and XXVII (145°).

The boundaries (dots) of the blocks, in Fig. 2, are drawn with no consideration of their geological significances, but they are drawn only to

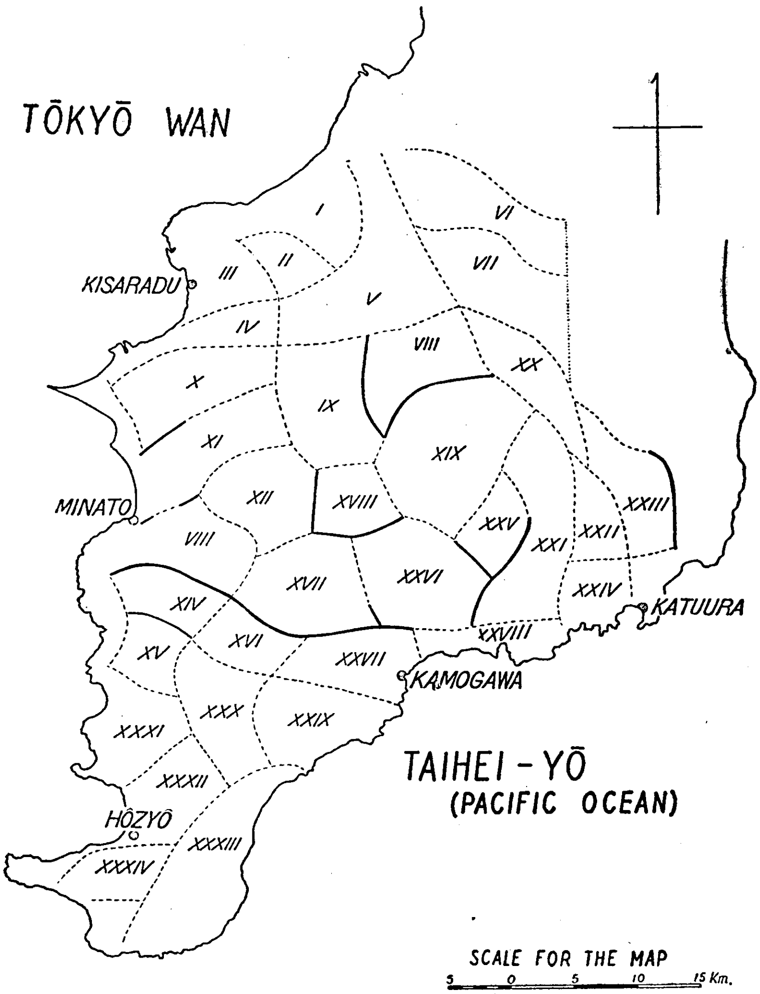

Fig. 6.

Probable Boundaries of the Blocks in Bôsô Peninsula. (The Boundaries coinciding with Tectonic Lines are drawn with Thick Full Lines.)

distinguish the areas within which the triangulation points belonging to respective groups or blocks are distributed. Among them, however, there are found several boundaries which are approximately coincident with the discontinuities significant in geologic structure. In Fig. 6, the boundaries of the blocks which are approximately coincident with geological faults located by Prof. H. YABE and his collaborators,[3] are drawn with full lines, while the boundaries with which the coincident tectonic lines are not yet known are shown by dotted lines.

Among these boundary lines of blocks coinciding with tectonic lines, the boundary lines between the group containing Blocks XIII, XVII and XXVI and that containing Blocks XIV, XVI and XXVII are most remarkable. As for these two groups of the blocks, we have mentioned that the directions of tiltings of the blocks are remarkably different. Corresponding to these boundary lines, there is a well known tectonic line across the peninsula from north of Kamogawa to Nokogiriyama.[4]

It may also be remarked that the result of the present investigation is qualitatively coincident with the result of Messrs. K. MUTÔ and K. ATUMI's investigation "into the result of the New and Old Measurements of the Levelling Net in the Kwantô District." In the present paper, block movements of the earth's crust in Bôsô Peninsula were investigated in more detail than the case of Messrs. K. MUTÔ and K. ATUMI's investigation.

3. Vertical Movements of Blocks.

In the preceding pages, we have exclusively dealt with the tiltings of the blocks. To interprete the full significance of the observed vertical displacements of triangulation points, it is necessary to consider also the translational vertical movements of the blocks as a whole besides the tiltings.

The vertical movement of a block is, in the present investigation, given by the mean value of vertical displacements of triangulation points distributed on the block.

Table I contains vertical movements of the blocks together with

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3) Prof. H. YABE was kind enough to lend me the geological maps of northern part of Bôsô Peninsula compiled by him and his collaborators, at the writer's disposal.

4) R. TAYAMA, *Saitô Hôonkwai, Gakuzyutu Kenkyu Hôkoku*, No. 9 (1930), etc.

5) K. MUTÔ and K. ATUMI, *Bull. E. R. I.*, 7 (1929), 495.

Table I.

Block	φ_m	θ_m (degree)	Vertical Movement
	$\times 10^{-5}$		cm.
I	1·75	10·0	13·7
II	10·44	270·0	25·3
III	5·20	28·0	15·8
IV	6·60	5·0	31·0
V	4·80	31·0	28·3
VI	4·20	46·0	24·8
VII	9·60	38·0	20·7
VIII	9·50	107·0	27·8
IX	10·00	52·0	69·7
X	5·20	38·0	58·3
XI	9·30	355·0	2·7
XII	5·10	7·0	125·6
XIII	6·90	321·5	125·3
XIV	5·10	261·0	126·5
XV	8·20	343·0	132·0
XVI	4·80	211·5	123·3
XVII	5·60	55·0	118·4
XVIII	21·40	23·0	83·3
XIX	6·60	89·0	32·2
XX	8·50	240·0	39·0
XXI	10·20	100·0	54·6
XXII	1·28	73·0	30·8
XXIII	3·10	215·0	29·0
XXIV	4·00	156·0	28·8
XXV	14·40	70·0	32·0
XXVI	8·30	76·0	63·3
XXVII	10·20	145·0	87·2
XXVIII	3·50	11·0	45·7
XXIX	7·00	145·0	102·7
XXX	13·10	212·0	128·3
XXXI	8·20	282·0	128·0
XXXII	6·60	340·0	141·9
XXXIII	9·95	94·0	128·6
XXXIV	6·60	230·0	154·5

the directions and magnitudes of their tiltings. Fig. 7 shows the geographical distribution of vertical movements of the blocks. In Fig. 7,

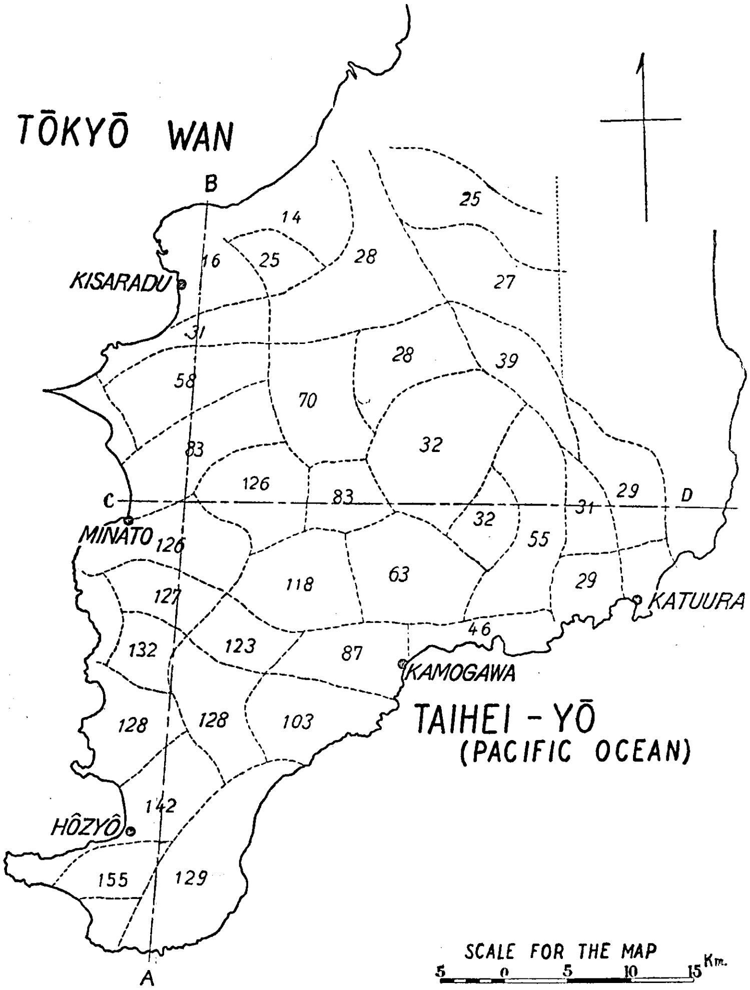

Fig. 7. Translational Vertical Movements of the Blocks in Bôsô Peninsula. (The Numeral Figures are the Amounts of the Vertical Movements in cm.)

we notice three groups of blocks, in each of which the vertical movements of the block are approximately the same.

They are:

1) A group of the blocks situated in the southwestern part of the peninsula, of which the vertical movements are 120–130 cm, including Blocks XXXII (142 cm) and XXXIV (155 cm) with exceptional upheavals;

2) A group of the blocks adjacent to N. and E. of the group 1), of which the vertical movements are 60–80 cm; and

3) A group of the blocks adjacent to N. and E. of the group 2), of which the vertical movements are 20–30 cm, except for Blocks XXI (55 cm) and XXVIII (45 cm) with greater upheavals. Blocks situated in the northern part of this group are less in amounts of vertical movements than those situated in the southern part, by 10 cm or more.

From the result obtained above, we can build a model of block movements in Bôsô Peninsula. Figs. 8 and 9 show the elevations of the model of block movements along the sections *AB* and *CD* of Fig. 7, the scales for the vertical movements and tiltings being much enlarged.

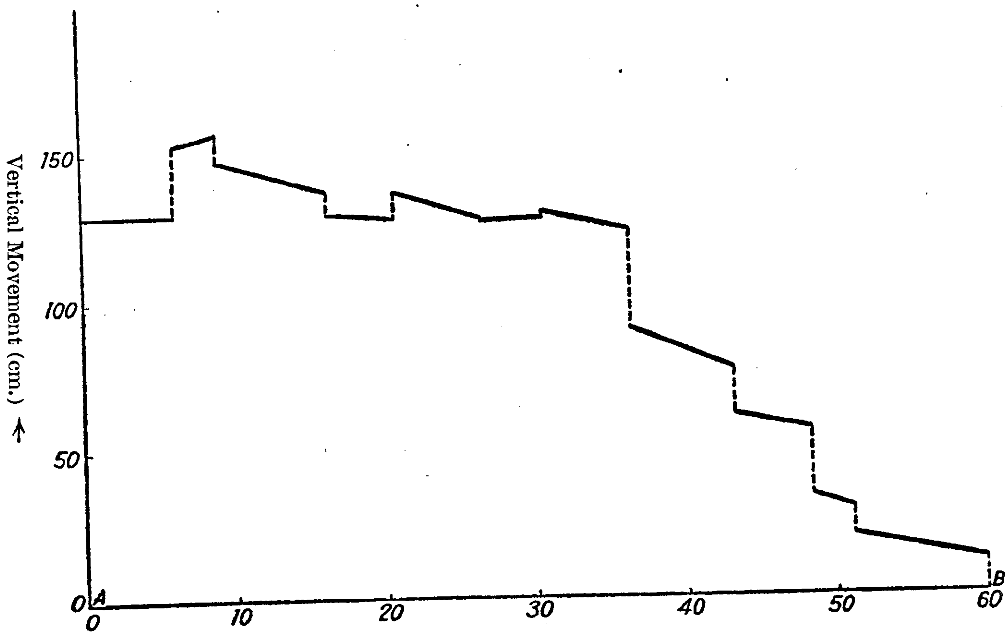

Fig. 8. The Elevation of the Section AB of the Model of the Block-Movements.

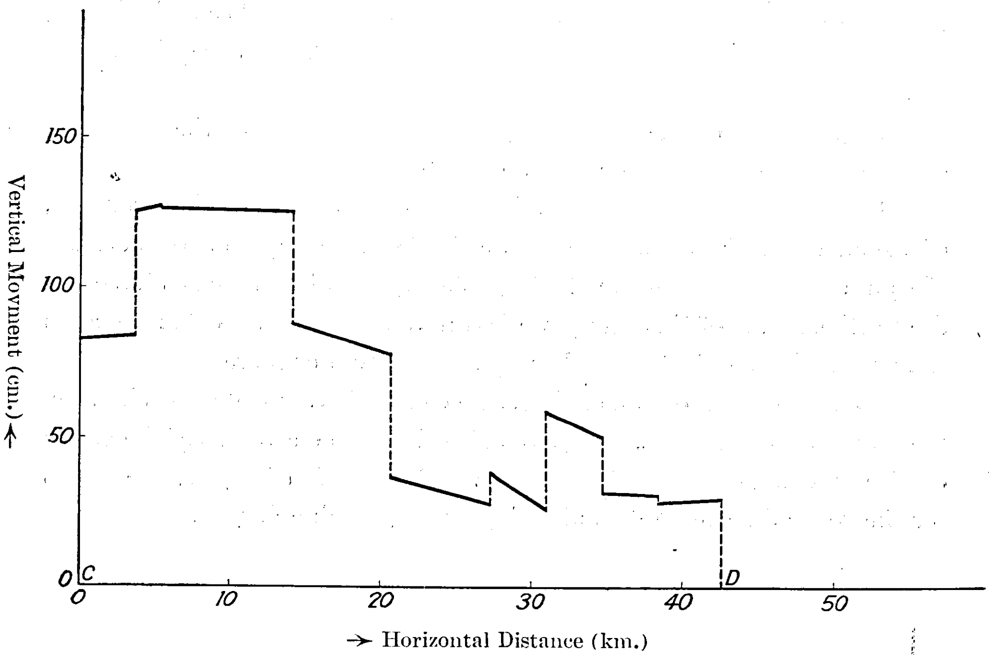

Fig. 9. The Elevation of the Section CD of the Model of the Block-Movements.

4. Horizontal Displacements of Triangulation Points in the District under Consideration.

In the above, we have investigated the block movements referring exclusively to the data of vertical displacements of triangulation points. On the other hand, the horizontal displacements of the triangulation points have been also measured. In the district under consideration, however, the horizontal displacements of triangulation points do not show so evident a block-character, as Dr. C. TSUBOI has found regarding the horizontal displacements of triangulation points in Tango Province.[6] Tables II, III, IV and V contain magnitudes (r) and directions (λ) of

6) C. TSUBOI, *Proc. Imp. Acad.*, 6 (1930), 56; *Bull. E. R. I.*, 8 (1930), 153.

Table II. (Block XVII)

Locality of Triangulation Points	r (m)	λ (degree)
Narikawa	1·320	128
Komatimine	1·358	124
Higasikuti	1·270	128
Uenohara	1·310	129
Terakado	1·407	132
Toyooka	1·447	138

Table III. (Block XXVI)

Locality of Triangulation Points	r (m)	λ (degree)
Izumi	1·301	119
Motokiyosumi	1·434	118
Utizumi	1·398	117
Simidu	1·332	119
Kase	1·346	120
Takatenzin	1·258	118
Nisino	1·259	118
Oomi	1·264	121
Suzuri	1·278	124

Table IV. (Block XXVII)

Locality of Triangulation Points	r (m)	λ (degree)
Asamiduka	1·292	127
Issenzyô	1·127	121
Uehara	1·141	117
Hotokeduka	1·259	118
Sengenyama	1·259	118
Mineoka	—	—

Table V. (Block XXIX)

Locality of Triangulation Points	r (m)	λ (degree)
Tenmen	0·781	129
Ogawa	0·706	139
Hasiragi	1·422	148
Kaminoyama	0·564	116
Makado	0·790	129
Karasuba	0·981	134
Dôbone	1·230	143

horizontal displacements of triangulation points distributed respectively on Blocks XVII, XXVI, XXVII and XXIX. As seen in the tables, in Blocks XVII, XXVI and XXVII, the magnitudes and directions of the horizontal displacements of the triangulation points approximately the same, while, in Block XXIX, they are much different from each other. There are many other blocks, in each of which, the magnitudes and directions of the horizontal displacements of the triangulation points are much different from each other, as seen in the case of Block XXIX.

This discordance of magnitudes and directions of the horizontal displacements of the triangulation points within the same block may be due to the facts that the horizontal displacements of the triangulation points are measured relative to certain fixed points,[7] while the block might be deformed in itself. We consider, for simplicity's sake, the case that there is no horizontal deformation in the block. In this case, horizontal displacements of the triangulation points in the block may be the same in both magnitudes and directions, if the horizontal movement of the block was purely translational relative to the fixed points. When, however, the block was rotated about a vertical axis, magnitudes and directions of the horizontal displacements of the triangulation points are expected to be much different from each other. Fig. 10 shows a plan of an ideal case in

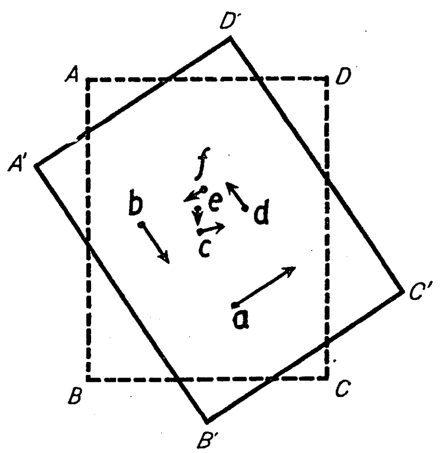

Fig. 10.

which the position of a rectangular block *ABCD* (dotted) has changed its position to *A′ B′ C′ D′* (full), after a block movement. The points *a*, *b*, *c*, *d*, *e* and *f* on the block are found to have moved in the directions of respective arrows, the lengths of which denote the magnitudes of the horizontal displacements of the points.

7) On calculating the present data of horizontal displacements of triangulation points in Kwantô District, 6 primary triangulation points were taken as fixed, which are situated in the outermost zone, surrounding the district, where the triangulation points with their horizontal displacements measured are distributed.

As a matter of fact, we notice a similar phenomenon near Rokudizô, one of the fixed primary triangulation points. Fig. 11 shows the hori-

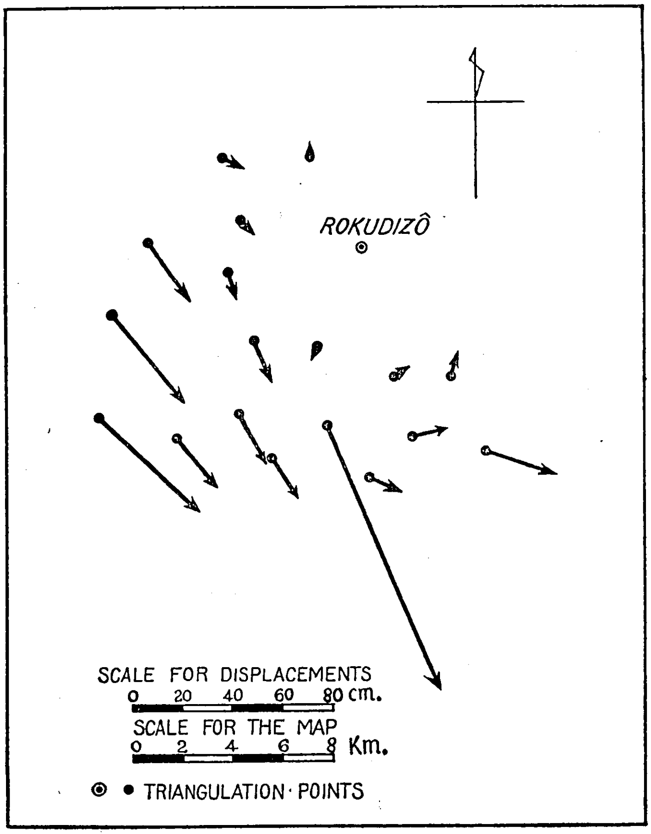

Fig. 11. Horizontal Displacements of Triangulation Points in the Neighbourhood of Rokudizô.

zontal displacements of triangulation points in the neighbourhood of Rokudizô.

Thus we cannot say that the triangulation points are not on a single block by the mere fact that the magnitudes and directions of their horizontal displacements are much different from each other. Hence, the horizontal displacements of triangulation points are not convenient for determining the forms and extents of constituent blocks in the earth's crust, at least in our present case.

As for the horizontal deformation of each constituent block, the investigation is reserved for a future communication.

In conclusion, the writer wishes to express his sincere thanks to Professor T. TERADA for his kind advices and guidance. The writer's thanks are also due to Professor H. YABE for his kindness in lending the valuable geological maps to the writer, which was compiled by his collaborators.

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18. 地塊とその運動 第一報

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水準點又は三角點の垂直變動量を知つて、地塊及びその傾斜運動を求めやうとする時に、近接する二點の垂直變動量及びそれらの位置から、その二點を結ぶ方向 (θ) 及びその方向に於ける垂直變動量の gradient ($\tan\phi$) を測れば、同一地塊内に在る點については、

$$\tan\phi = \tan\phi_m \cos(\theta - \theta_m) \qquad (1)$$

なる關係が成立つ故、比較的容易に地塊とその傾斜運動とを知ることが出來る。ϕ_m, θ_m は夫々、その地塊の傾斜角度と、傾斜した方向とを示す量である。

筆者は、房總半島内に於ける二三等三角點の垂直變動量を資料とし、(1) の關係を用ひて、同半島内の地塊運動の模樣を調べてみた。

水平移動量については、丹後地方に於ける坪井助教授の見出された樣な地塊的な模樣は見られない。地塊がある垂直軸のまわりに廻轉運動をした樣な場合には、同一地塊内で、水平移動の大いさも方向も異り得る故、水平移動によつて地塊を定めやうとする試は、この場合不適當である。實際の場合についても、上述の樣な模樣が見える。又、前述の方法で定めた地塊内に於ける三角點の水平移動を見ても、そろつてゐるものも二三あるが多くの場合は、同一地塊内で方向も大いさも著しく異つてゐる。
