

22. Notes on the Block Structure of the Earth's Crust.

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1. In previous paper¹⁾, the writer tried to show from analyses of the vertical displacements of triangulation points distributed in the Kwantô district, that the earth's crust could be regarded as consisting of a number of crustal blocks. From analyses of the vertical displacements of bench-marks, similar blocks were found also in a number of other districts as well²⁾, the boundaries of which approximately coincided with faults and other tectonic lines determined by geologists, as was the case in the Kwantô district.

The horizontal dimensions of these crustal blocks in the Tango and other districts were found to be roughly 10 km, while those of the Kubiki block, the tilting movements of which were first pointed out by the late Professor N. Yamasaki, is approximately 50 km³⁾. It will however be noticed after closer investigation of its movements that the Kubiki block is apparently composed of several smaller blocks, each having horizontal dimensions of about 10 km.

The horizontal dimensions of the crustal blocks in the Kwantô district are also about 10 km. It may also be worthy of notice that the distribution of the mean vertical displacements of each block reveals the existence of larger ones containing several primary blocks⁴⁾, the horizontal dimensions of which are from about 40 to 50 km, as may be estimated from Fig. 1.

In connection with the block structure of the earth's crust in the Kwantô district, it may be noticed that it consists of horizontal layers, as shown by Dr. T. Matuzawa, who has determined it seismologically.

1) N. MIYABE, *Bull. Earthq. Res. Inst.*, **9** (1931), 256 ; **9** (1931), 409 ; **11** (1933), 639.

2) C. TSUBOI, *Bull. Earthq. Res. Inst.*, **7** (1929), 103 ; *Jap. Journ. Astr. Geophys.*, **6** (1933), 95.

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

4) By primary block is meant those having horizontal dimensions of about 10 km, after usage in the preceding paper, *loc. cit.* 1).

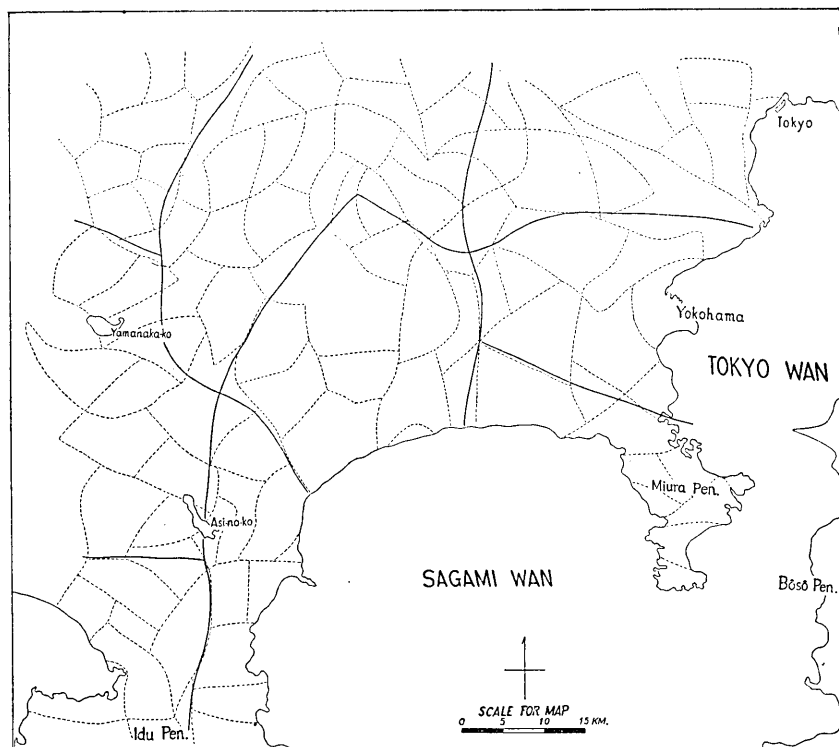


Fig. 1. Block structure in the Kwantô district.
(Full lines denote estimated boundaries of larger blocks.)

2. According to Dr. Matuzawa⁵⁾, the earth's crust in the Kwantô district is composed of three different layers, in each of which the velocities of propagation of the *P*- and *S*-waves are different. The depths of these layers and the velocities of the *P*- and *S*-waves as determined by Matuzawa for each layer are shown in Table I.

Table I.

No. of layer	Depth	V_P	V_S
I	0~20 km	5.0 km/sec	3.15 km/sec
II	20~50	6.1	3.7
III	>50	7.5	4.45

From these data, we can calculate the values of the Poisson's ratio for the respective layers by using the relation

5) T. MATUZAWA, *Bull. Earthq. Res. Inst.*, 6 (1929), 117.

$$2\sigma = \frac{\left(\frac{V_p}{V_s}\right)^2 - 2}{\left(\frac{V_p}{V_s}\right)^2 - 1},$$

where σ is the Poisson's ratio, V_p and V_s are the velocities of the P - and S -waves respectively. The Poisson's ratio thus calculated for each layer is given in Table II.

Table II.

No. of layer	Depth	Poisson's ratio
I	0~20 km	0.17
II	20~50	0.21
III	>50	0.23

It will be noticed from the foregoing table that the Poisson's ratio for the superficial layer is remarkably small, to explain which there may be several theories. The writer will attempt here to find some connection between this fact and the block structure of the earth's crust.

The Poisson's ratio σ is connected with other elastic constants, that is, Young's modulus E and compressibility k by the relation

$$\sigma = \frac{1}{2} \left(1 + \frac{1}{3} kE \right).$$

The values of σ therefore become smaller as kE become larger. For ordinary homogeneous isotropic materials, the values of k and E are generally of the order of 10^{-12} and 10^{12} respectively.

We could picture to our minds a certain model, the values of elastic constants of which are nearly those of the crustal layers obtained from data of velocities of seismic waves. Such a model would represent the block structure of the earth's crust.

3. We have some hints useful in forming an idea of block structure, such as the following:

(i) As has been shown experimentally by W. A. Zisman⁶⁾, the values of Poisson's ratio of several rocks of porous structure are generally much smaller than those of the substance composing the rocks.

(ii) The approximate horizontal dimensions of the blocks, as already shown, are 10 km and 40 km corresponding to the thicknesses of the upper layers, namely 20 km and 50 km.

(iii) As has been shown by Prof. T. Terada⁷⁾, a layer of powder,

6) W. A. ZISMAN, *Proc. Nat. Acad. Sci., U. S. A.*, **19** (1933), 653.

7) T. TERADA and T. WATANABE, *Proc. Imp. Acad.*, **10** (1934), 143.

when disturbed from below, is, as a rule, broken into blocks, the horizontal dimensions of which are of the same order of magnitude as their thickness.

(iv) The fact that contiguous blocks, as have been shown in the preceding investigations, tilted and moved in entirely different ways, suggests the presence of some substance that is much softer than the rigid blocks that fills the spaces between the rigid blocks. As has been shown by Prof. K. Sezawa⁸⁾, if the boundaries of rigid blocks were directly in contact with each other, there would be so much friction on the contacting surfaces that the block movements referred to would scarcely be possible.

From these considerations, we can imagine a model of crustal layers consisting of rigid blocks and soft materials filling the interstices of the blocks. When seismic waves are propagated through such layer with a period of several seconds, that is, with wave length comparable with or larger than the horizontal dimensions of the individual blocks, the stress distribution in such layers may be similar to those in the porous material, that was yielded, in which case the effective value of the Poisson's ratio will be smaller. Should however the period of oscillation of the seismic waves propagated in such layers be 1 sec. or less, the horizontal dimensions of the rigid blocks become several times the wave lengths, in which case the model of the mechanism such as just described becomes unsuitable for showing that the Poisson's ratio becomes smaller.

4. We shall next consider a model similar to that mentioned above, that is, the crustal layer consisting of rigid and soft substances arranged alternately in horizontal direction, as shown in Fig. 2. In the model shown in this figure, the densities, elastic constants, and the horizontal dimensions of the rigid and soft substances are $\rho_1, \lambda_1, \mu_1, L_1$ and $\rho_2, \lambda_2, \mu_2, L_2$, respectively. We then assume the following for the sake of simplicity:

- (i) The seismic waves propagated in the layers are plane waves and the wave front is perpendicular to the direction of propagation.
- (ii) The boundaries of blocks of both the rigid and soft substances are also perpendicular to the direction of propagation of the waves.

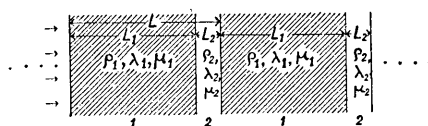


Fig. 2. Schematic configuration of the block structure. The arrows show the direction of propagation of seismic waves.

8) K. SEZAWA, *Bull. Earthq. Res. Inst.*, 10 (1932), 1.

(iii) The horizontal dimensions L_1 and L_2 of the alternate rigid and soft substances are constant, so that we may take the mean velocity of the substances $L_1 + L_2$ as that of the layers.

(iv) The velocities of propagation of the seismic waves in the two different substances are determined separately by the elastic constants of the substances composing the respective layers.

With these assumptions, we get the following calculations:

$$\frac{L}{Vp_m} = \frac{L_1}{Vp_1} + \frac{L_2}{Vp_2} = \frac{L}{Vp_1} \left\{ 1 - \frac{L_2}{L} \left(1 - \frac{Vp_1}{Vp_2} \right) \right\},$$

$$\frac{L}{Vs_m} = \frac{L_1}{Vs_1} + \frac{L_2}{Vs_2} = \frac{L}{Vs_1} \left\{ 1 - \frac{L_2}{L} \left(1 - \frac{Vs_1}{Vs_2} \right) \right\}^9,$$

where $L = L_1 + L_2$, Vp_1 , Vp_2 are velocities of the P -waves and Vs_1 , Vs_2 those of the S -waves in substances 1 and 2 respectively, while Vp_m and Vs_m are the mean velocities of the P - and S -waves. The effective value of Poisson's ratio in such layers will then be

$$\sigma = \sigma_0 \left\{ 1 - \frac{L_2}{L} \sqrt{\frac{\mu_1 \rho_2}{\mu_2 \rho_1}} \left(\frac{\sqrt{3\mu_2 - \sqrt{\lambda_2 + 2\mu_2}}}{\sqrt{\lambda_2 + 2\mu_2}} \right) \right\},$$

where σ_0 is the Poisson's ratio of the rigid substance which has been taken as $1/4$ or 0.25 .

Since, as in an actual case, when σ is less than $1/4$, λ_2 is less than μ_2 and the numerical values of λ_2 , μ_2 may be taken at orders of magnitude smaller than λ_1 , $\mu_1^{10)}$, the coefficient of L_2/L becomes larger than unity. Writing the equation in the simpler form,

$$\sigma = \sigma_0 (1 - \beta L_2/L),$$

the values of $\beta L_2/L$ each can be calculated from the actual values given in Table II to be

0.32, for layer I,

0.16, for layer II.

If then we assume $L_2/L = 1/10$ for layer I, we have $\beta = 3.2$ and $L_2/L = 0.5/10$ for layer II. The assumed value of $1/10$ for layer I and the

9) A similar idea regarding the existence of larger blocks was proposed by Prof. S. Ono, based on the fact that the "Laufzeit" curves are regarded as consisting of segments of curves.

Cf. S. Ono: *Kensin-Zihô*, 5 (1925), 51, 111, and 221, (in Japanese).

10) A substance filling the interstices between the rigid blocks, we can imagine, for instance, such substance as compose superficial mud or gravel layers, the elastic constants of which are of the order of 10^{10} , as measured by Mr. Haeno and others.

Cf. S. HAENO, I. MIKAWA, T. HAGIWARA and R. YOSIYAMA, *Disin*, 4 (1932), 465, (in Japanese).

calculated value of $L_2/L=0.5/10$ for layer II are of the same order of magnitude in the matter of errors in determining the approximate extent of the blocks from the data of vertical displacements of triangulation points and bench-marks. Hence, even were there regions of soft rocks as supposed in the above mentioned model, the data of vertical displacements will give us no inkling of their existence.

If therefore there is any likelihood that the assumption just referred to is a first approximation, the idea of block structure for the earth's crust may be plausible, and even if the solution were not unique, it will at any rate be one way of explaining the smallness of σ in the upper layer as deduced from the propagational velocity of seismic waves.

22. 地殻の地塊的構造に就て

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三角點又は水準點の垂直變動から推定される地塊の大きさは、10 km 程度のものと 40~50 km 程度のものが比較的著しく目立つてみえる。關東地方では、之に相應して、地表から 20 km 及 50 km の厚さの水平層が、地震波の研究から知られ、尙、其等の層のポアソン比を地震波の傳播速度から求めると 0.17, 0.21 等普通に認められてゐる 0.25 よりは著しく小さいものを得る。

地殻が多くの地塊より成り、其等の地塊がかなり自由な運動をなし得る事實などを考慮しつつ、嘗つて、小野教授が、地震波の走時曲線が多くの曲線の segments から成るさういふ事實に基いて考へられた地塊構造の考へを小區域にまで延長して、ポアソン比の見掛け上小さくなる事と地塊構造を關聯させて考へてみた。