53. *On Depression of the Earth's Crust in Honzyô and Hukagawa, Tokyo.*

By Naomi MIYABE,

Earthquake Research Institute.

(Read July 21, 1932.—Received Sept. 20, 1932.)

1. The result of the recent precise levelling along the routes passing through Honzyô and Hukagawa, Tokyo, shows remarkable depressions of the bench-marks distributed in this region. Among them, B. M. 9832, situated at Higasi-Hirai-tyô, and B. M. 3378, situated at Kayaba-tyô, were depressed more than 15 cm. during 1930–1931. A zone including these two bench-marks are regarded as the zone of maximum depression. In the preceding paper,[1] it was pointed out that the zone of maximum depression was coincident with the zone in which several wells yielding methane gas were located. The zone of maximum depression was shown also as coincident with a valley in the Tertiary surface features, reproduced from the data obtained by the authorities of the Reconstruction Bureau. In his recent investigation, Prof. A. Imamura has regarded this zone of maximum depression as the west boundary of Kôtô Block.[2]

2. As the matter of fact, the bench-marks in Honzyô and Hukagawa have been depressed considerably since the Kwantô Earthquake of 1923.

On the other hand, there is not a portion in Honzyô and Hukagawa where the level of the ground surface is much higher than 3 m. above the mean sea level. If, therefore, the general feature of the ground surface is represented by the present heights of the bench-marks in this region and the depression of the earth's crust continues with the rate with which it is now being depressed, it is a matter of worry to predict that the ground of this region may surely go down into the water in scores of years hereafter. Total amounts of depressions during 1925–1931 and the heights in 1925 and in 1931 of the bench-marks in this region are given in Table I.

As shown in the table, the heights of the bench-marks have been

---

1) N. MIYABE, *Proc. Imp. Acad.*, 7 (1931), 344.

2) A. IMAMURA, *Jap. Journ. Astro. Geophys.*, 8 (1931), 177.

Table I.

B. M.	Locality	Heitght 1926	Displacement (1926—1931)	Height (1931—VII.)
		m.	mm.	m.
0	Yokoami	1·8241	− 62·4	1·7617
3379	Koidumi-tyô	1·1776	−221·2	0·9564
3378	Kayaba-tyô	0·9432	−734·5	0·2087
3377	Kameido	1·6711	−319·0	1·3521
9831	Hukagawa Kôen	1·3283	−287·2	1·0411
9832	Higasi Hirai-tyô	0·8350	−532·6	0·3024
9833	Sunamati	0·9303	−210·9	0·7194
9834	,,	0·1339	−304·7	−0·1708
			(1926—1930)	(1930—II-III.)
		m.	mm.	m.
3375	Higasi Komatugawa	1·2877	−160·9	1·1268
3376	Nisi ,,	0·6871	−193·8	0·4933
9835	Matue-mati	2·5138	−124·2	2·3996
9836	Kasai-mura	1·7273	−121·5	1·6058

so much lowered that, in 1931, B. M. 3378 (Kayaba-tyô) stands at 0·2087 m., B. M. 9832 (Higasi-Hirai-tyô) at 0·3024 m. and B. M. 9834 (Suna-mati) at −0·1708 m. above the mean sea level. Hence, if the houses are built on the ground surface at such a height that is represented by the present heights of the bench-marks, it is possible that they should be inundated at high tide, since the maximum range of the semi-diurnal tide in Tokyo Bay a little exceeds 2 m. In autumn of the last year (1931), the newspaper reported for several times that the houses in Hukagawa were inundated at high tide. In Fig. 1, the shaded areas represent the flooded areas at high tide of the last autumn. It is said that the houses are inundated at high tide in the season, from summer to autumn, in these two or three years, and that the height of the flood in the last autumn was so conspicuous that a similar case was never experienced before, but for the cases due to heavy rains.

The land of Honzyô and Hukagawa was reclaimed after the Kwantô Earthquake of 1923, to keep the level of the ground surface at least 8 feet above the A. P. Level.[3] As the maximum range of the semi-diurnal tide in the Tokyo Bay does not much exceed 2 m., the land of Honzyô and Hukagawa should not be inundated at high tide, provided that

3) The A. P. Level is the level by 1·1344 m. lower than the mean sea level of Tokyo Bay which is taken as the standard datum for the heights of all bench-marks.

there had been neither a considerable depression of the land nor an abnormal rise of the water surface.

3. Mareographs are installed at several places in Hukagawa and the levels of the water are continuously recorded since before the Kwantô Earthquake under the supervision of the authorities of the Civil Engineering Bureau of the Municipality of Tokyo. Among these, the mareograph at Heikyû-tyô (marked by × in Fig. 1) is situated nearest to the zone of maximum depression mentioned in the preceding paper. By the courtesy of the municipal authorities of Tokyo, the author was able to review the mareograms taken at Heikyû-tyô.

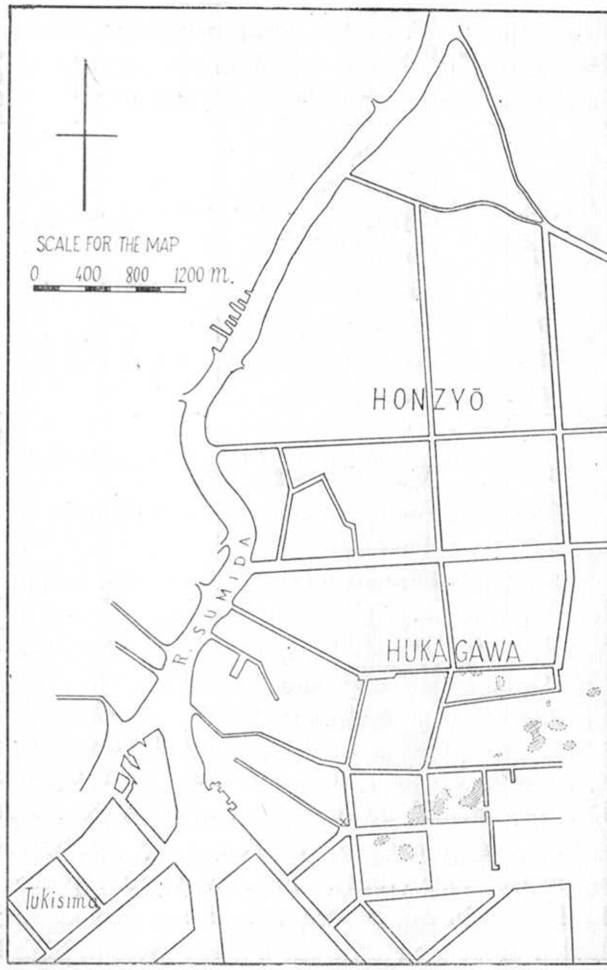

Fig. 1. Distribution of Flooded Areas in Hukagawa. Last Autumn (Nov. 1931).

In order to obtain the curve of the mean sea level at Heikyû-tyô, the heights of the water level was read on the mareograms at every hour. Heights of the water level thus obtained were averaged for every 29 days to diminish terms of semi-diurnal, diurnal and fortnight periods and the resulting curve is shown in Fig. 2. It must be remarked that the mareograms are not taken during the time interval April—May of 1926, as the mareograph was in disorder. After May 1926, the heights of the water level on the mareogram is referred to a different zero-line.

Hence, the curve of the mean sea level afterwards 1926 should be a little shifted to a higher position to continue to the curve obtained from the data of water levels during 1923–1926.

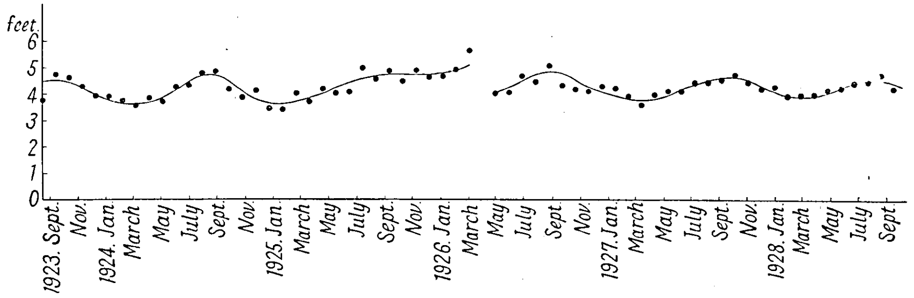

Fig. 2. 29 Day Mean Sea Level at Heikyû-tyô, Hukagawa.

Following facts are noticed in the curve of the mean sea level in Fig. 2.

a) The mean sea level oscillates with an approximate annual period. It is highest towards the end of summer and lowest towards the end of winter, the amplitude being about 30 cm. or less. This fact agrees with the phenomenon that the inundation in Hukagawa at high tide is experienced most frequently in summer and autumn.

b) In addition to the annual period in the change of the mean sea level there exists a secular change, as will be seen in Fig. 2. The mean sea level in 1926 is about 20 cm. higher than that in 1923. During the same period of time, the vertical displacements of B. M. 9831 was $-74{\cdot}5$ mm. The gradual rise of the mean sea level at Heikyû-tyô is, therefore, 2·7 times the amount of depression of B. M. 9831 during 1923–1926. This value of the ratio is approximately the same with the ratio of the amount of depression of B. M. 9831 to that of B. M. H–15 measured as had occurred during 1929–1932, the latter ratio being 2·4. As the bench-mark H–15 is situated very near the portion where the mareograph under consideration is situated, the secular upheaval of the mean sea level noticed in the mareograms taken at Heikyû-tyô may be regarded as the depression of the earth's crust, if the crust movement had been continued in the same sense since 1923, as that observed during 1929–1932. As for the vertical displacements of the bench-marks during 1929–1932, descriptions and discussions are given afterwards.

As a matter of fact, we cannot notice any sign of secular upheaval of the mean sea level in the curve afterwards 1926, while the earth's crust was deformed continuously in the same region. Here, it may be conjectured[4] that there had been an intentional adjustment of the reference lines on the recording paper. The conjecture is based on the facts that the amplitude of the annual variation of the mean sea level has been diminished sensibly since 1926 and that, when daily mean values of the sea level are plotted instead of 29 day mean values, the mean position cannot be represented by a simple periodic curve, but interrupted by sudden jumps as shown in Fig. 3.

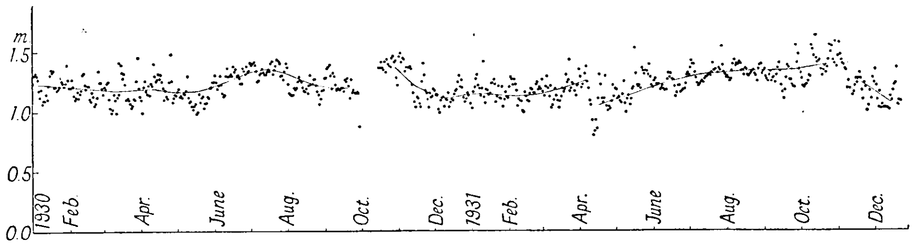

Fig. 3. Daily Mean Sea Level at Haikyû-tyô, Hugagawa.

4. On account of frequent inundations in Hukagawa at high tide and remarkable depressions of the bench-marks shown as the results of recent precise levellings carried out by the authorities of the Military Land Survey, the municipal authorities of Tokyo decided to carry out a revision of precise levelling survey in the region of Honzyô and Hukagawa, where the former survey was carried out by the same authorities in Nov. 1929.

There are 42 bench-marks distributed in Honzyô and Hukagawa including Tukisima, 33 of which are installed by the municipal authorities,[5] 4 of which by the authorities of the Reconstruction Bureau[6] and the remaining 5 bench-marks are installed by the authorities of the Military Land Survey.[7]

The geographical distribution of these bench-marks is shown in Fig. 4.

The revision of the precise levelling was carried out in Jan.-April of this year (1932), and the vertical displacements of these bench-marks measured which had occurred during these 2·3 years. The amounts of vertical displacements of these bench-marks are given in Table II.

4) The conjecture was ascertained afterwards.
5) Shown by marks ● and numerals with prefix H or Z.
6) Shown by marks ○ and numerals with prefix R.
7) Shown by marks ⊙ and numerals with prefix M.

Table II.

B.M.	Locality	Vertical Displacement ΔH. During Nov. 1929—March 1932.
M—J-O	Kyôbasi, Sin Hunamatu-tyô	− 3·9mm
H— 1	Hukagawa, Aikawa-tyô 18	− 69·1
H— 4	„ Kiyozumi-tyô 7	−186·9
H— 5	„ Mihuna Kuramaye-tyô 33	−163·9
Z—15	Honzyô, Titose-tyô 55	− 37·9
M— 0	Honzyô, Yokoami	− 13·9
M—3379	„ Koizumi-tyô	− 92·0
R—32	Honzyô, Yokoami	− 99·7
Z— 1	Honzyô, Omote-tyô 43	− 10·4
Z— 2	„ Nakanogô-Kawara-mati 1	− 17·5
Z— 8	„ Nakanogô-Narihira-tyô	—
Z— 6	„ Yanagisima-Moto-mati 186	−175·0
Z— 7	„ Yanagisima-mati	−206·7
M—3378	Honzyô, Kayaba-tyô	−284·5
H— 8	Hukagawa, Honmura-tyô	- 235·6
H— 9	„ Senda-mati	−298·0
M—9832	Hukagawa, Higasi-Hirai-tyô	−208·0
H—12	Hukagawa, Higasi-Hirai-tyô	−152·6
H—13	„ Kiba-mati 13	−371·2
M—9831	Hukagawa, Hukagawa-Kôen	−137·4
R—35	Hukagawa, Monzen-Yamamoto-tyô	−216·9
Z— 3	Honzyô, Sumida-Kôen	− 39·1
Z— 4	„ Susaki-tyô 179	− 97·5
Z— 5	„ Ukedi-mati 75	—
Z—10	„ Isiwara-tyô III-2	−151·6
Z— 9	„ Taihei-tyô I-62	−209·7
Z—14	„ Hayasi-tyô I-2	−119·6
Z—11	„ Midori-tyô II-3	−168·0
Z—12	„ Kikukawa-tyô I-3	−313·5
Z—13	„ Hayasi-tyô II-89	−190·1
H— 7	Hukagawa, Higasi-Ôgibasi 25	−145·7
H— 2	„ Zaimoku-tyô 12	−221·1
H— 3	„ Nisi-Hirano-tyô 6	−177·5
H— 6	„ Higasi-Daiku-mati 62	−226·0
H—10	„ Miyosi-tyô 1	−124·6
H—11	„ Nisi-Hirai-tyô 73	−152·1
H—14	„ Susaki-Benten-tyô I-17	−118·9

(to be continued.)

Table II. (*continued.*)

B.M.	Locality	Vertical Displacement ΔH. During Nov. 1929—March 1932
H—15	Hukagawa, Huruisiba	$-322 \cdot 0^{\text{mm}}$
H—16	„ Hamazono-tyô	−128·6
H—17	„ Ettyûzima-mati 8	−228·2
H—18	„ Ettyûzima-mati 1	− 54·1
R—15	Kyôbasi, Sin-Tukudazima	9·0
R—13	„ Tukisima	6·0

Errors of the measurements are, of course, not so small. But, as the amounts of the vertical displacements are large enough, the general feature of the deformation of the earth's crust may not be much affected by these errors.

In analysing the present data of vertical displacements of the bench-marks distributed in Honzyô and Hukagawa, the whole area is divided into six regions. Corresponding to Regions I, II, III and IV respectively, Blocks with their magnitudes and azimuths of their tiltings are determined by using as the data the vertical displacements of the bench-marks, through the relation

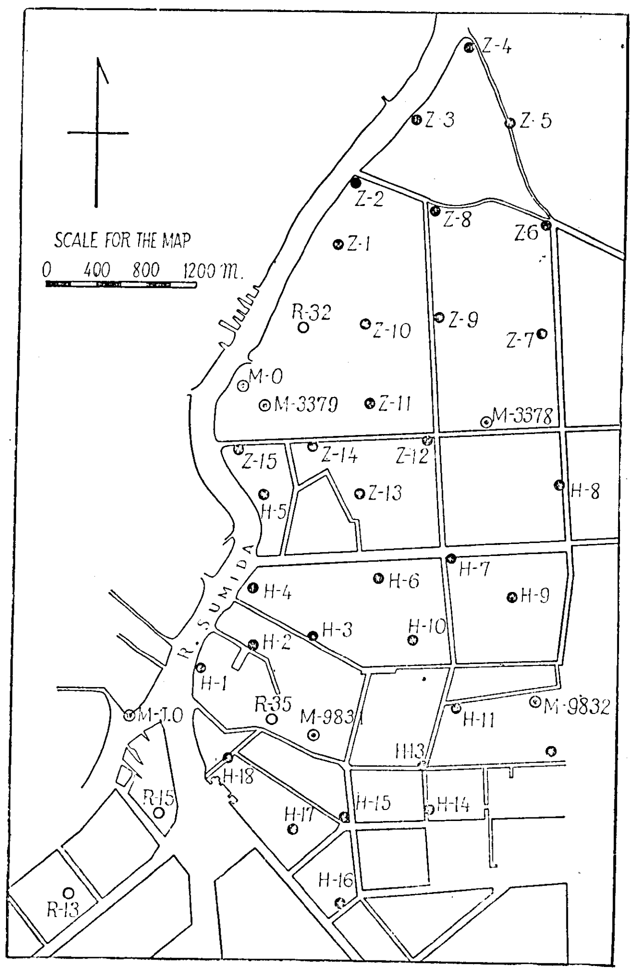

Fig. 4. Distribution of Bench-marks in Honzyô and Hukagawa.

$$\tan \varphi = \tan \varphi_m \cos (\theta - \theta_m),$$ [8]

where φ_m and θ_m are magnitude and azimuth of tilting of Block respectively.

The azimuths and magnitudes of tiltings of these blocks are determined graphically as shown in Figs. 5a, 5b, 5c and 5 d. The numerical values of φ_m and θ_m of tiltings and the mean vertical displacements, $\overline{\Delta H}$, of these blocks are given in Table III.

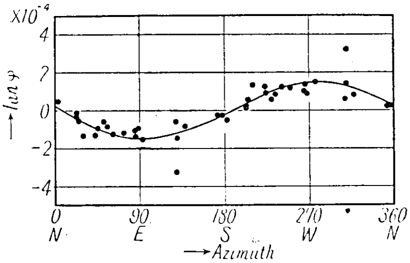

Fig. 5 a. Graph determining φ_m and θ_m of Block I.

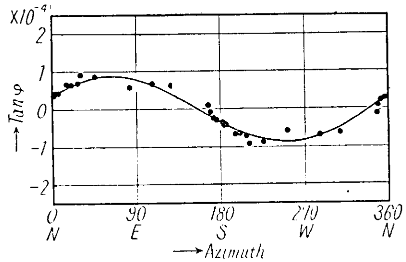

Fig. 5 b. Graph determining φ_m and θ_m of Block II.

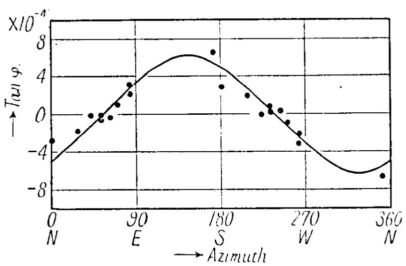

Fig. 5 c. Graph determining φ_m and θ_m of Block III.

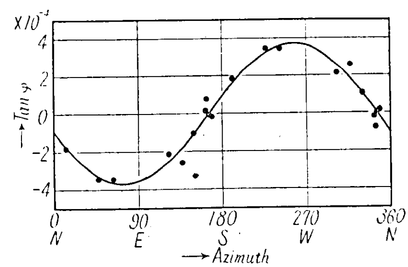

Fig. 5 d. Graph determining φ_m and θ_m of Block IV.

Table III. Magnitudes and Directions of Tiltings and Mean Vertical Movements of Blocks.

Block	Direction of Tilt. Referred to N. θ_m	Magnitude of Tilt. φ_m in 10^{-4}	Mean Vertical Move. $\overline{\Delta H}$ in mm.
I	99° (S 81° E)	1·5	− 97·5
II	247° (S 67° W)	0·86	−252·2
III	326° (N 34° W)	6·3	−241·2
IV	76° (N 76° E)	3·7	−157·9
V	—	—	−167·1

8) N. Miyabe, *Proc. Imp. Acad.*, 7 (1931), 150. *Bull. Earthq. Res. Inst*, 9 (1931), 256.

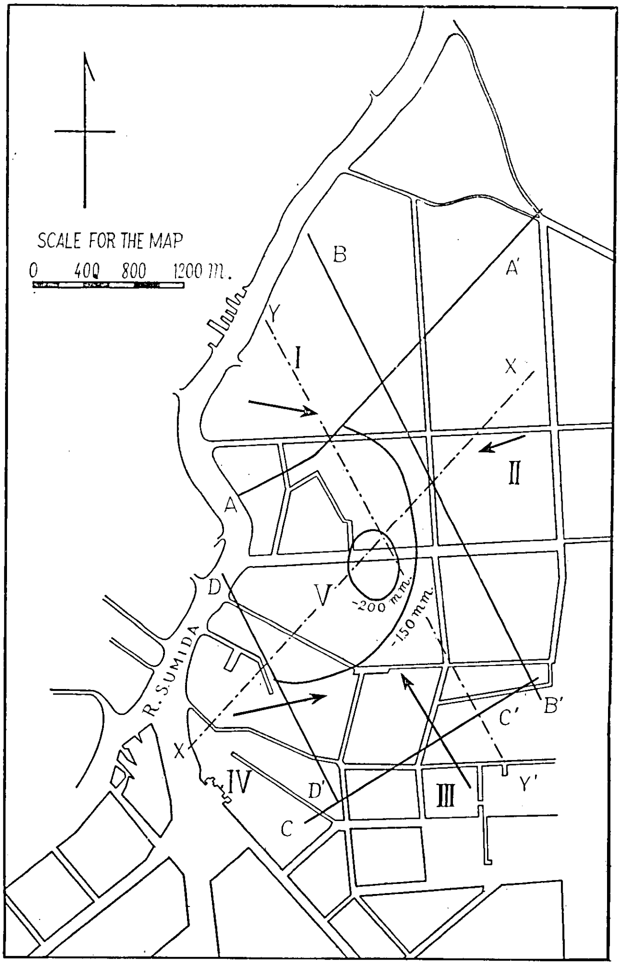

Fig. 6. Block Movements and Deformation of the Earth's Crust in Honzyô and Hukagawa.

As for the Region V, a plane or a tilted block cannot be determined as in the case of Regions I–IV. But the contours lines of equal depression are so simply drawn (as shown in Fig. 6) that the earth's crust in this region was deformed, speaking exaggeratedly, into the shape of a bowl.

It is noticed with interest that the arrows in Fig. 6, representing the vectors of tilting motions of Blocks I–IV, are directed towards Region V, where the earth's crust is deformed in the manner referred to above. Unfortunately the mode of deformation of the earth's crust in the sixth region, i. e., the northern most region is not clearly determined for the lack of the data of vertical displacements of the bench-marks Z–5 and Z–8.

In Fig. 7, profiles of sections XX' and YY' in Fig. 6 are shown with much exaggerated vertical scale. Blocks III and IV are strongly tilted towards NW and NE respectively and the zones including the boundaries of these two blocks to Region V are exceedingly depressed. Amount of depression in this zone exceeds 30 cm. in these 2·3 years.

It may be remarked that the regions which inundated at high tide are approximately coincident with the zones including the boundaries

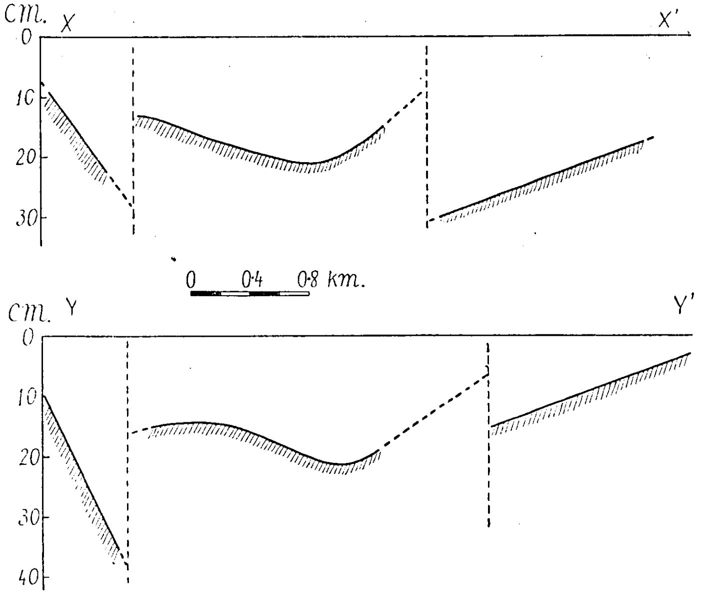

Fig. 7. Profiles of Deformed Surface of Earth (Section XX' and YY' in Fig. 4).

of Blocks III and IV to Region V.

5. The boundaries of Blocks or Regions determined in the present investigation are significant in the results of the investigations by other authors; i.e., Boundary BB' corresponds to the west boundary of Kôtô Block determined by Prof. A. Imamura[9] from different data, and Boundary AA' is coincident with the boundary of the blocks determined by Messrs. K. Muto and K. Atumi[10] from another data.

In the preceding paper,[11] we have pointed out the coincidence of the zone of maximum depression including B.M. 9832 and B.M. 3378 with a valley in the Tertiary surface features. To investigate the matter in more detail, the surface feature of the Tertiary Bed in the region of Honzyô and Hukagawa was thoroughly reproduced from the data obtained by the authorities of the Reconstruction Bureau. The map of Fig. 8 shows the surface features of the Tertiary Bed in Honzyô and Hukagawa thus reproduced. In the figure, $\gamma\gamma'$ denote the valley in the Tertiary surface features previously remarked. This central line denoting the course of the valley is directed from NE to SW. By connecting

9) A. Imamura, *loc. cit.* 2).

10) K. Muto and K. Atumi, *Bull. Earthq. Res. Inst.*, **7** (1929), 495.

11) N. Miyabe, *loc. cit.* 1).

axis of troughs in the surface feature of Tertiary Bed, we can draw the lines $\alpha\alpha'$, $\beta\beta'$, and $\delta\delta'$, besides $\gamma\gamma'$, as shown in Fig. 8 by broken lines.

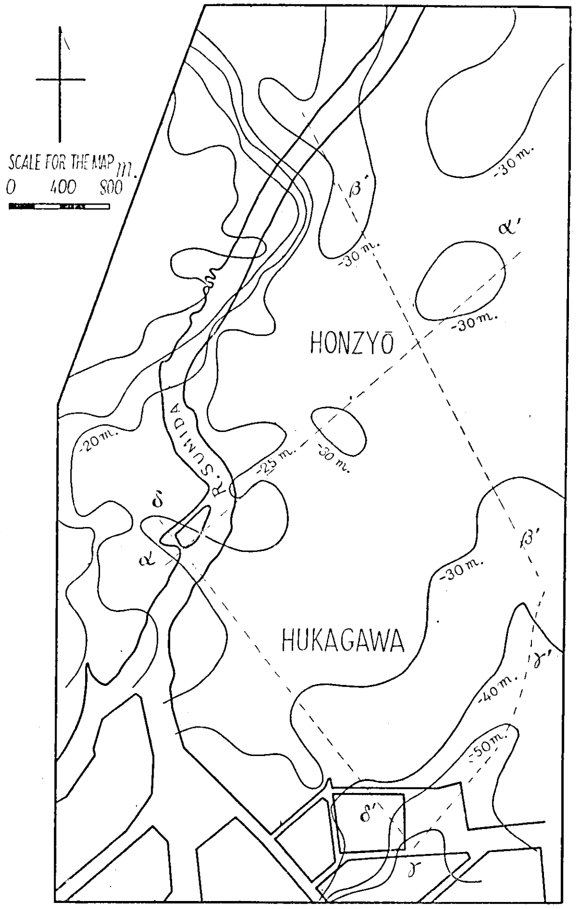

Fig. 8. Tertiary Surface Feature in Honzyô and Hukagawa.

In comparing the configuration of the trend of the boundary lines of blocks in Fig. 7 with that of the lines in Fig. 8, we notice that the lines AA', BB', CC' and DD' representing the boundaries of the blocks in Fig. 7 are respectively corresponding to the lines $\alpha\alpha'$, $\beta\beta'$, $\gamma\gamma'$ and $\delta\delta'$ in Fig. 8.

The fact above referred to, taken together with another fact that the rate of downward crust movement in the region under consideration seems to be accelerated in these several years,[12] suggests us that the

12) N. MIYABE, *Bull. Earthq. Res, Inst.*, 10 (1932), 597.

present mode of deformation of the earth's crust is neither simply due to the settling of fillings in the reclaimed land nor due to local disturbances limited to the very point where each bench-mark is situated.

6. We have at present no evidences for explaining the course of the depression of the earth's crust in Honzyô and Hukagawa. It may, however, be possible to consider that the deformation of the earth's crust due to the weight of fillings added to the earth mass of the reclaimed land contributes, in some measure, to the actual amounts of depression recently measured. The reclamation was carried out in Honzyô and Hukagawa by piling up the muds to a thickness of several metres to keep the level of the ground surface 8 feet above the A. P. Level. The order of magnitude of the depression which might have been caused by the weight of the fillings may be estimated by a simple calculation based on a probable assumption from two different points of view, as will be shown in the following.

a) Suppose that the earth's crust was depressed elastically by surface loading, i.e., by the weight of the fillings in the reclaimed land, then we have the following expression for the vertical displacement, w, after Boussinesq,

$$w=-\frac{1}{4\pi\mu}\frac{\partial^2}{\partial z^2}\int r\,dP+\frac{2\lambda+3\mu}{4\pi\mu(\lambda+\mu)}\int\frac{dP}{r}.$$

Assuming that the surface loading is uniform over the circular area of radius R, the vertical displacement, w, at the periphery of the circular area is given by Prof. H. Nagaoka,[13] in the form

$$w=\frac{\lambda+2\mu}{\pi\mu(\lambda+\mu)}\rho g h R,$$

where $\rho g h$ corresponds to the load on a unit area, ρ is the density and h is the thickness of the fillings. In the present case, the following numerical values may be adopted as probable:

$\rho=2{\cdot}0.$

$\delta=1/4$ (Poisson's ratio).

$g=9{\cdot}8\times10^2$ cm./sec.

$h=5$ m.

$R=2$ km.

$\mu\fallingdotseq10^{10}$ c.g.s.[14]

13) *c.f.* H. NAGAOKA, *Publ. Imp. Earthq. Inv. Com.*, No. 22 B (1906), 1.

14) Prof. S. KUSAKABE has shown that E (Young's modulus) of the wet sandstone is $3{\cdot}2\times10^{10}$ c.g.s.; S. KUSAKABE, *ibid.*, No. 22 B (1906), 27.

Then we have

$$w \doteqdot 12 \text{ cm.}$$

The estimated depression in this case is a little smaller than the actual depression, but of the same order of magnitude. The amount of depression estimated above, indicates the depression at the periphery of the area of surface loading. Hence, the amount of depression at the centre[15] of the area will be a little greater, i.e., closer to the actual amount of depression.

b) Suppose that the earth's crust consisted of a material like a mass of sand, and the density is uniform. By piling up the fillings to the thickness of h, the region surrounding the reclaimed land was upheaved, i.e., the reclaimed land was depressed, say, by w. Then we have the relation, after the theory developed by Prandtl,

$$\frac{w}{h} = \frac{1-\sin\rho}{1+\sin\rho} e^{-\pi \tan\rho},$$

where ρ is an angle of repose of the sandy crust.

Substituting

$$h = 5 \text{ m.},$$

and

$$\rho = 30^\circ,$$

in the above relation, we have

$$w \doteqdot 28 \text{ cm.}$$

The estimated amount of depression, in this case, is closer to the actual amount of depression.

Thus, the estimated amounts of depression as calculated above are of the same in order of their magnitudes with each other and also with those of actual depression. Hence, it may be thought possible, if not probable, that the actual depression measured by the revision of the levelling survey contains an effect due to elastic or plastic deformation of the earth's crust caused by the surface loading, i.e., the weight of the fillings in the reclaimed land.

In conclusion, the present writer wishes to express his sincere thanks to Professor Torahiko Terada for his kind advices and guidance

15) The amount of depression at the centre is given by

$$w = \frac{\lambda+2\mu}{\pi\mu(\lambda+\mu)} \rho g h R.E(0).$$

Substituting the numerical values referred to above, we have

$$w \doteqdot 18 \text{ cm.}$$

and to Late Professor Kyoji Suyehiro for his kind advices and encouragements. Cordial thanks are also due to Messrs. Y. Otuka, T. Takayama, S. Kawasima and T. Watanabe, for their valuable assistances, and to the Municipal Authorities of Tokyo for their kindness in placing the valuable data at the writer's disposal.

---

53. 本所及び深川に於ける土地の沈降

地震研究所　宮　部　直　巳

本所深川方面に在る陸地測量部の水準點が年々著しく沈降することは既に前報告に於いて注意した所であるが、昨年（昭和六年）秋には、大潮の滿潮時に深川方面一帶が海水の浸入を受けるに至つた。この浸水は、尤も、それ以前にもあつたのであるが、昨年は一層甚だしかつたといふことである。一方に於いて、平久町に設置されてゐる検潮儀の記錄からは平均海水面が 1923—1926 の間に徐々に上昇してゐたことが知られた。此に於いて、東京市土木局では、本年（昭和七年）一月から四月に亘つて、本所深川方面の水準測量を遂行した。水準點は陸地測量のものの外、復興局及び東京市土木局のものを加へて合計四十二個あり、從つて、その水準測量の結果、深川方面の土地の變形狀況が一層詳細に知られることになつた。本文に於いては主としてその結果を取扱つたものである。

敍上の水準測量によつて知られた各水準點の垂直變動を解析した結果は次の如く要約される。

i) 本所深川一帶を六個の部分に分けることが出來、その中の四個については、各部分内にある水準點の垂直變動量を、その各部分がそれぞれ傾斜せる地塊であるとして說明し得る。是等四個の地塊は第五の部分を圍繞して存し、而も、各地塊の傾斜の方向は何れもこの中心部分を指してゐる。又この中心部分における變形は凹形の椀の如き形を示してゐる。

ii) 各地塊の境界は夫々他の方面よりも意味あるものの如く、その一は、今村博士の定められた江東地塊の西緣と一致し、他の一は、武藤、熱海兩氏が、他のデータから定められたものと一致する。又是等の境界線は、復興局に於いて調査されたデータから決定されたこの方面の第三紀層の表面地形にあらはれてゐる低地を連ねた線とも略〻一致する。

以上の垂直變動が何によつて起されたかは未知の問題に屬するけれども、地表を埋立てた埋土の荷重による、彈性的又は可塑性的變形として期待される變動量は、測量の結果得たものと、オーダーに於いては一致する。從つて斯樣な意味の變形もこの場合全然無視して考慮の外に置くことは出來ないのではないかと思はれる。
