12. *The Ogasima Earthquake and Its Aftershocks.*

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Introduction.

The strong earthquake that occurred in the neighbourhood of Ogasima, a small peninsula in Akita Prefecture, at 14 h 58 m, May 1, 1939, demolished several hundreds of dwelling houses in the peninsula and killed 29 persons.[1] Shocks, almost the same in severity, occurred twice with an interval of about 2 minutes. On the seaside, the damage was increased by landslips caused by the earthquake. The distribution of demolished houses, except those due to landslips, is shown in Fig. 1.

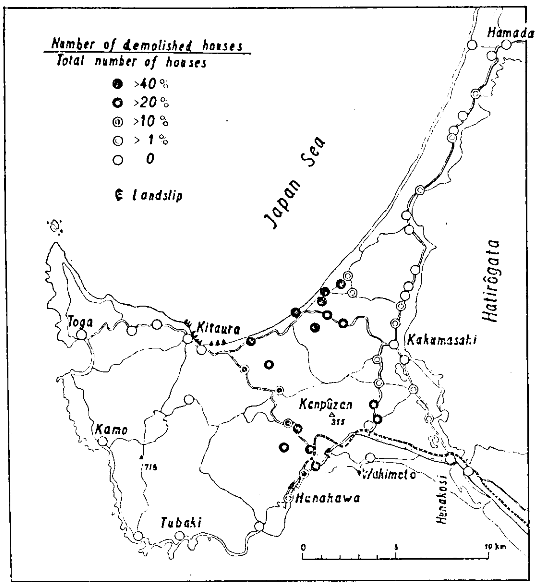

Fig. 1.

Epicenter of the Earthquake.

Seismological data obtained at stations within a radius of 200 km from the epicenter are shown in Table I,[2] from which it will be seen that Akita is the only station near the epicenter, the others being more than 100 km away, making precise determination of the epicenter difficult. In this case, the epicenter was determined graphically by means of the formula $D=kt$, where D is the hypocentral distance, t the duration of the preliminary tremors, and k the constant. But since the S-phase of such a shallow earthquake does not appear sharply on the seismograms, to read off the duration of the preliminary tremors is in general very difficult. It is unavoidable that the reported values of the duration of the preliminary tremors should contain large

1) T. HAGIWARA, *Bull. Earthq. Res. Inst.*, 17 (1939), 627 (in Japanese).

2) *Kisyô-yôran*, Centr. Meteor. Obs., May 1939 (in Japanese).

Table I.

Station	Akita	Sendai	Yamagata	Morioka	Aomori	Mizusawa
Duration of the preliminary tremors (in sec).	6·7	28·2	26·5	18·0	15·9	24·5

Hatinohe	Miyako	Hakodate	Niigata	Hukusima	Mori
22·4	25·9	25·5	23·6	37·5	35·7

errors, except at stations lying in the neighbourhood of the nodal line of the push-pull distribution of the initial motion, where the P-phase (initial motion) is very small, but where, on the contrary, the S-phase is large, so that the duration of the preliminary tremors is accurately read off. From this standpoint, the epicenter was determined with much reliance on the values of the four stations in the neighbourhood of the nodal line of this earthquake, namely, Akita, Aomori, Sendai, and Yamagata. In Fig. 2, circles with radius kt are drawn with their centers at the respective stations, putting $k=7{\cdot}9$, which is known as the value of k for near earthquakes with very shallow foci. In this way, it was determined that the epicenter lay about ten kilometers north of the peninsula ($\varphi=40°02'N$, $\lambda=139°47'$), the depth of the focus being about 20 km.

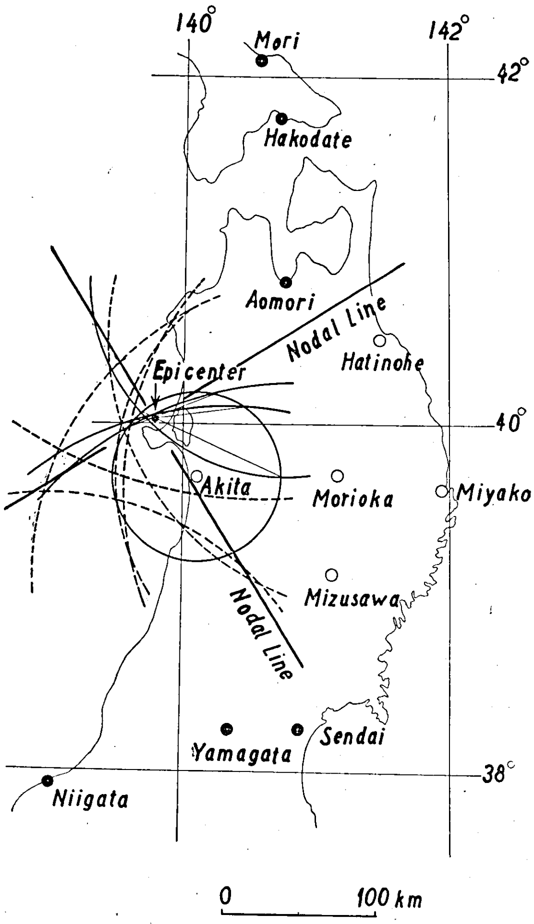

Fig. 2. ●—push. ○—pull.

As to the earthquake that occurred about 2 minutes after the first one, no seismological data were obtained, because, when the second earthquake occurred, the tremors due to the first earthquake had not yet ceased, so that the phases for the second earthquake could not be read off from the seismograms. However, in the northern regions, the first earthquake was felt more strongly than the second, while the latter was felt more strongly in the peninsula and in regions southwards[3], which puts the epicenter of the second earthquake near the peninsula (see Fig. 3).

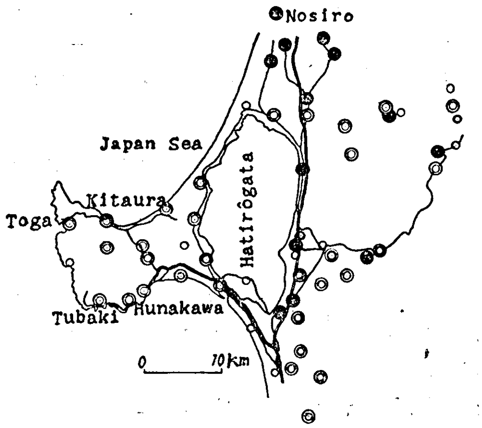

Fig. 3
• The first earthquake was felt more strongly.
◎ The second earthquake was felt more strongly.
○ The first earthquake and the second one were same in severity. (After A. Imamura)

Aftershocks.

For observing the aftershocks, the writer, on May 2, took four portable seismographs with him to this district. They were first installed at Tutisaki, Nosiro, Hunakawa, and Kitaura. Observations having showed that the earthquake activities were confined to the neighbourhood of the peninsula, the two seismographs at Tutisaki and Nosiro were removed to Kakumasaki and Hunakosi, thus contracting the seismographic network, but since later, many of the earthquakes seemed to be generated in the western region of the peninsula, the seismograph at Hunakosi was again removed to Tubaki. The observations were continued until the 26th of the same month. The elements of the seismograph used here are

Mass of pendulum	Component	Period	Damper	Magnification	Driving rate of recording paper
7·5 kg	A horizontal component	0·12 sec	Air damper	100	1 mm/sec

At each place the recording drum was driven by a synchronous motor, except at Tubaki, where a clock was used as no current was obtainable in the daytime. At Kitaura, a clock was resorted to in the beginning of the observations.

For determining the position of the hypocenters, the ordinary method in which the duration of the preliminary tremors are used was

3) A. IMAMURA, *Disin*, 11 (1939), 372 (in Japanese).

employed. In this case, the first requisite is to evaluate k in the formula $D=kt$, which was determined by numerical calculation, using the duration of the preliminary tremors at the four stations. If we consider a rectangular coordinate, taking the x and y axes in a horizontal plane, and the z axis vertically downward, we get[4)]

$$(X-x_n)^2+(Y-y_n)^2+z^2=k^2t_n^2, \qquad (1)$$
$$n=0,\ 1,\ 2,\ 3.$$

where (X, Y, Z) is the coordinate of a hypocenter, $(x_n, y_n, 0)$ that of the stations, and t_n the corresponding duration of the preliminary tremors. For convenience, the coordinate is taken as x_0, y_0, y_1 being nil. From equation (1), the coordinate (X, Y, Z) and k may be determined. First, k is given by

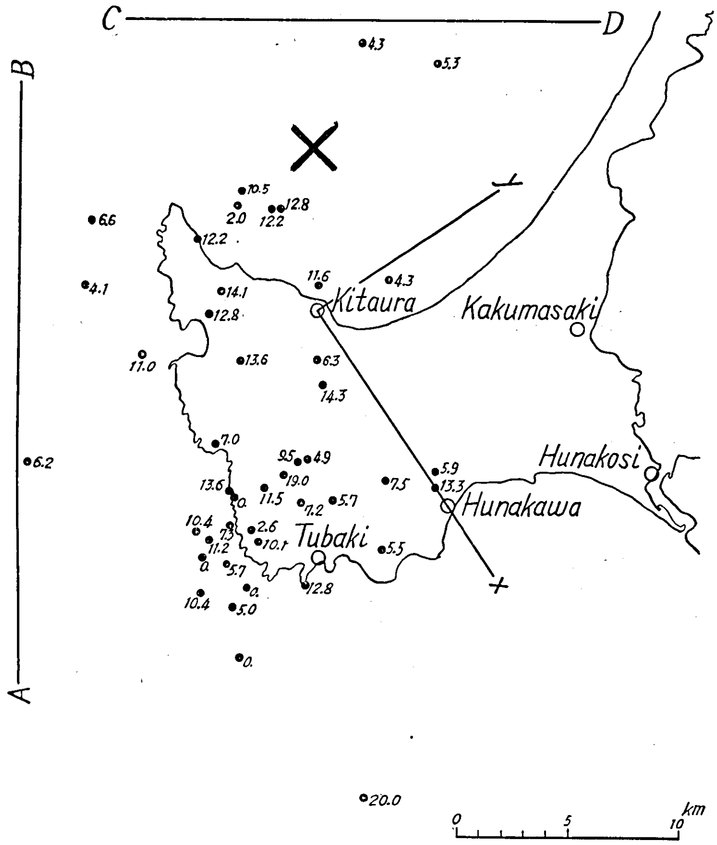

Fig. 4. Distribution of epicenters, the numerals showing the depth of foci. ×—Epicenter of the first severe earthquake.

4) N. Nasu, *Bull. Earthq. Res. Inst.*, 6 (1929), 245.

$$k=\sqrt{\frac{d_1^2(x_3y_2-x_2y_3)-(d^{2}y_2-d_2^2y_3)d_1}{\tau_1(x_3y_2-x_2y_3)+(y_3\tau_2-y_3\tau_2)d_1}}, \qquad (2)$$

$$\tau_1=t_1^2-t_0^2,\ \ \tau_2=t_2^2-t_0^2,\ \ \tau_2=t_3^2-t_0^2,$$

where d_1, d_2, and d_3 are respectively the distances of $(x_1, 0, 0)$, $(x_2, y_2, 0)$, and $(x_3, y_3, 0)$ from the origin $(0, 0, 0)$. In the present case, $(x_1, 0, 0)$,

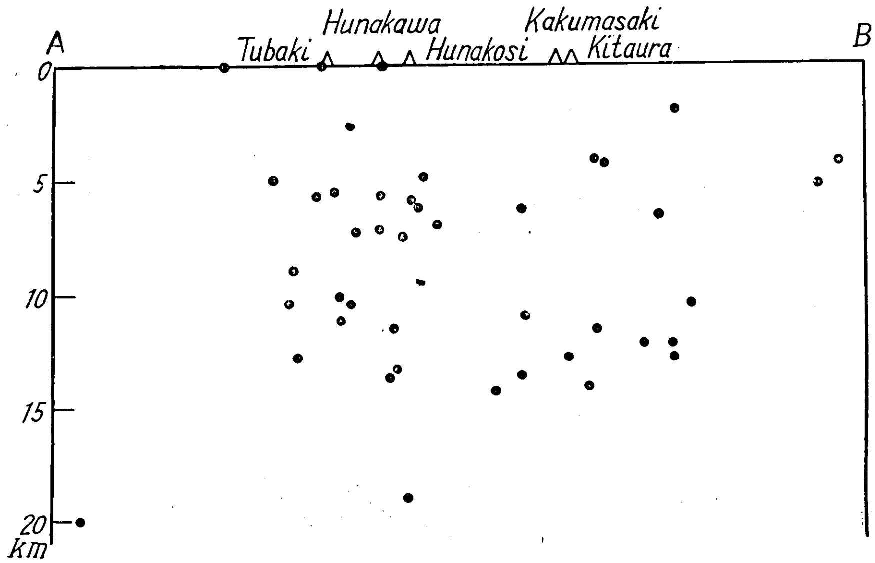

Fig. 5. Projection of hypocenters on a vertical plane.

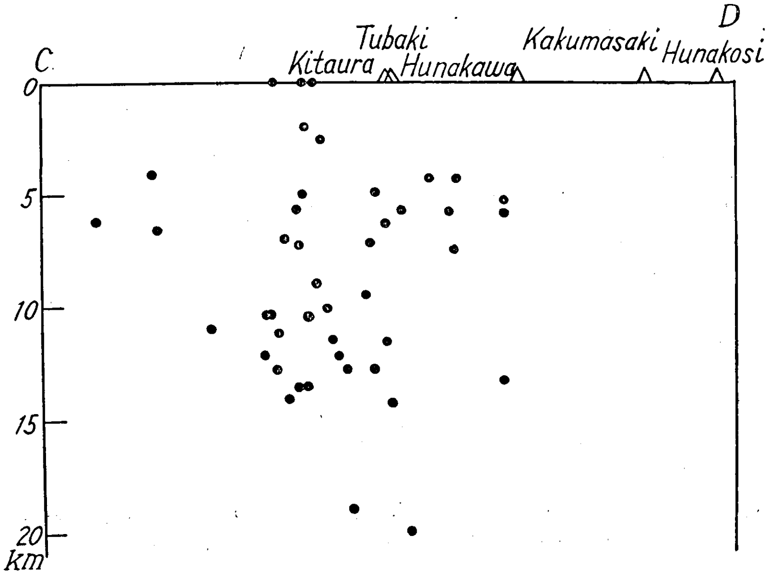

Fig. 6. Projection of hypocenters on a vertical plane.

Table II.

Date			Kitaura		Hunakawa		Kakumasaki		Hunakosi		Tubaki		k
			t_0	Δk	t_1	Δk	t_2	Δk	t_3	Δk	t'_3	Δk	
d	h	m	sec		sec		sec		sec		sec		
9	0	30	2·2	−0·27	3·8	+0.53	4·4	+0·75	5·3	−1·00			5·0
9	0	32	2·7	−0·30	3·9	+0·50	4·0	+0·62	4·9	−0·84			4·9
9	1	34	2.9	−0·28	3.9	+0·43	4·2	+0·57	5·0	−0·75			4·7
10	4	14	2·8	−0·35	3·5	+0·50	4·0	+0·70	4·6	−0·88			5·1
13	15	46	2·0	−0.17	2·5	+0·24	3·6	+0·43	4·1	−0·55			4·9
14	21	50	2·7	−0·43	3·7	+0·67	4·1	+0.91	4·8	−0·90			5·5
20	21	22	3·1	+0·19	2·2	+0·53	4·1	−0·49			1·1	−0·20	4.9
20	22	19	2·3	+0·18	3·2	+0.96	3·2	−0·48			3·3	−0·75	5.3
23	7	01	1·6	+0·10	1·6	+0·41	2·8	−0·36			1·3	−0.25	5·0
23	7	50	2·9	+0·26	2·6	+0·91	3·7	−0·64			2·2	−0·59	5·0

Δk shows the deviation in k when a deviation of 0·1 sec is given to t_0, t_1, t_2 or t_3.

Table III.

Date			Kita-ura	Huna-kawa	Kaku-ma-saki	Huna-kosi	Date			Kita-ura	Huna-kawa	Kaku-ma-saki	Huna-kosi	Tu-baki
d	h	m	sec	sec	sec	sec				sec	sec	sec	sec	sec
7	23	20	2·6	2·3		4·3	14	5	28	3.4	3·1		4·6	
8	12	01	2·4	2·2		4.1	14	7	45	2·8	2·8		4·1	
8	12	48	3·5	2·9		4·1	14	11	21	1·3	2·1	2·6		
8	15	28	3·1	3·0		4·5	14	18	10	2·6	4·0		4·6	
9	0	30	2·2	3·8	4·4	5·3	14	21	41	3·1	2·6	4·1		
9	0	32	2·7	3·9	4·0	4·9	14	21	49	2 7	3·7	4·4		
9	0	44	2·4	3·9	3·8		14	21	50	2·7	3·7	4·1	4·8	
9	1	34	2·9	3·9	4·2	5·0	15	0	42	2·6	3·9	3·8		
9	4	50	2·5		4·6	5·6	16	20	33	1·2	3.2	3·2		
9	5	45	3·1		3·5	5·6	17	0	10	2·5	2·4	3·8		
10	4	14	2·8	3·5	4·0	4·6	17	13	56		4·8	6·1		4·5
10	16	55	3·2	3·3	4·3		19	8	48	2·9	3·2	3·6		
10	23	41	2·2	1·6	2·6		19	9	18	2·5	4·2	3·2		
11	5	38	3·0	3·0	4·3		19	20	59	3·2	2·6	3·2		
11	16	07	2·4	1·3	2·8		20	6	7	2·9	2·3			1·3
12	8	03	2·7	4·0	4·2		20	21	22	3·1	2·2	4·1		1·1
12	12	13	2·1	1·2	2·1		20	22	19	2·3	3·2	3·2		3 3
12	13	40	2·3	2·3	3·3		22	22	13	2·0	1·5			1·2
12	17	48	4·0	4·0		4 9	23	7	01	1·6	1·6	2·8		1·3
13	9	35	2·2	1·9		3·4	23	7	50	2·9	2 6	3·7		2·1
13	15	46	2·0	2 5	3 6	4·2	23	11	26	2·1	1·8			0·8
13	21	01	1·1	2·2	1·9		25	10	19	1·8	1·9			0·9

$(x_2, y_2, 0)$, and $(x_3, y_3, 0)$ were taken respectively at Kitaura, Hunakawa, and Kakumasaki, $(x_3, y_3, 0)$ being taken first at Hunakosi and then at Tubaki (Fig. 4). The earthquakes used for this purpose are shown in Table II. For the mean value, $k=5{\cdot}1\pm0{\cdot}3$ was obtained.

When the value of k has been determined, the coordinate of the hypocenter (X, Y, Z) may then be obtained, substituting the numerical values in the solution of equation (1), although, in practice, it is more convenient and sufficiently accurate to obtain the position of the hypocenter by a graphical method. In Fig. 4 are shown the distribution of about 50 epicenters of after-shocks that were obtained with the data of 3 stations by the graphical method, taking $k=5{\cdot}1$. The duration of preliminary tremors of the shocks used here are given in Table III. In Fig. 5 and 6, the hypocenters are projected on a vertical plane.

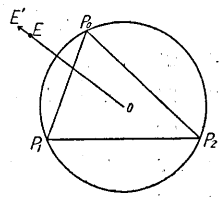

Fig. 7

Errors in Hypocentral Position.

The next step is to estimate the magnitude of the errors in the hypocentral positions determined as just described. As will be seen from Table III, a small deviation in the duration of the preliminary tremors results in fairly large deviation in the value of k. In the table, Δk was calculated by the equation

$$\Delta k = \frac{\partial k}{\partial t_n} \Delta t_n.$$

Although a value of 5·1 was obtained for the mean value of k, there may be an error. We shall now consider the effect of an error in the value of k on the position of the epicenter. In Fig. 7, if P_0, P_1, P_2 are seismic stations and E the epicenter, then the distance between E and the center (0) of the outer circle for the triangle P_0, P_1, P_2 is proportional to k^2, namely[5],

$$\overline{OE} = ck^2,$$

where c is a constant, whence the deviation $(\Delta\overline{OE})$ in $\overline{OE}$ with reference to the deviation (Δk) in k is given by

$$\begin{aligned}\Delta\overline{OE} &= 2ck\Delta k \\ &= 2\,\overline{OE}\Delta k/k.\end{aligned}$$

The deviation in epicentral position due to deviation in k is larger, the farther the epicenter is from the center of the outer circle. For

5) R. TAKAHASI, *Bull. Earthq. Res. Inst.*, 6 (1930), 231.

example, if k is increased by 1 %, the distance of the epicenter from the center of the outer circle of the triangle is moved outward by 2 %. The deviations in the epicentral position caused by increasing k by 0·3 are shown by vectors in Fig. 8.

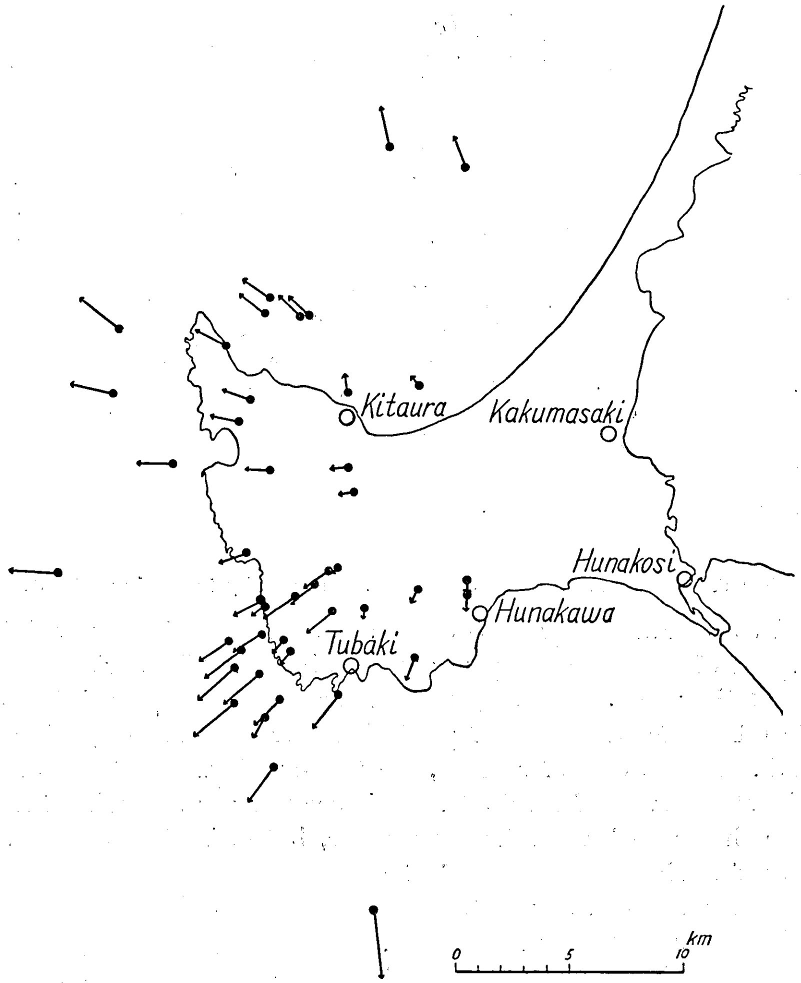

Fig. 8. Deviations in epicentral position caused by increasing k by 0·3.

As to the effect of deviation in the depth of the hypocenter, since no such simple relation as the foregoing could be found, the depth for k increased by 0.3 was obtained graphically for each earthquake and the deviation found accordingly (Fig. 9).

The effect of error in the duration of the preliminary tremors for each seismic station will next be considered. Since, in the present case, the recording drum, in a number of cases, was turned by a synchronous motor, the speed of rotation of the drum, and consequently the driving rate of the recording paper, is determined by the frequency cycle of the electric source, which was an ordinary lamp (50 cycle). At the time, the regulation of the cycle was good, the deviation in frequency being within 0·5 cycle. Actually, the time-marks were made on the

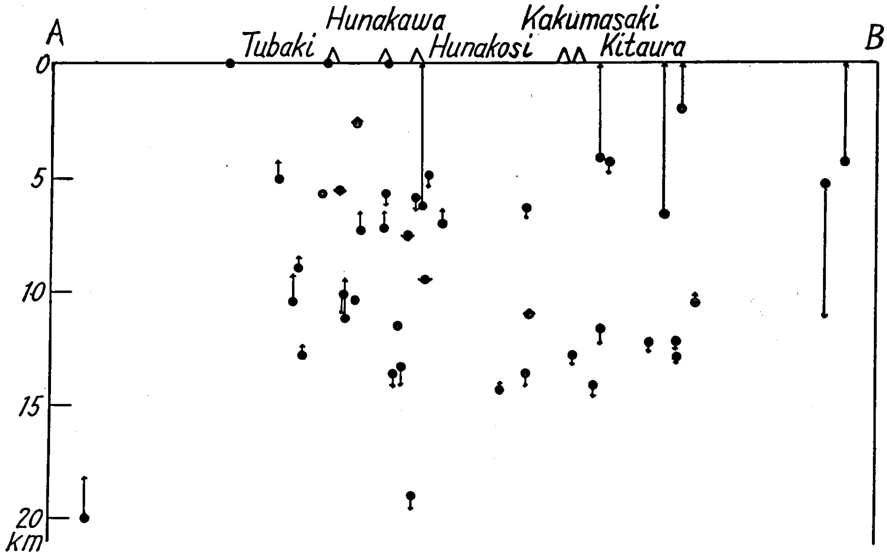

Fig. 9. Deviations in depth of hypocenter caused by increasing k by 0·3.

record at intervals of every 5 or 10 sec, as the occasion demanded, and the speed of the recording paper was calibrated. The deviation in the speed of the paper, therefore, does not exceed 1 %, so that it is reliable up to 0·1 sec for durations of preliminary tremors not exceeding a few seconds. In the case of a clock, the time-marks were set down continuously at intervals of 1 minute. This accuracy is somewhat less than that in the case of a synchronous motor, but it is also reliable up to 0·1 sec for short durations of the preliminary tremors, as was the case in Kitaura and Tubaki. Besides, since earthquakes in which the P and S phases could readily be seen were selected here, the errors in reading off the duration of the preliminary tremors are believed to be also less than 0·1 sec.

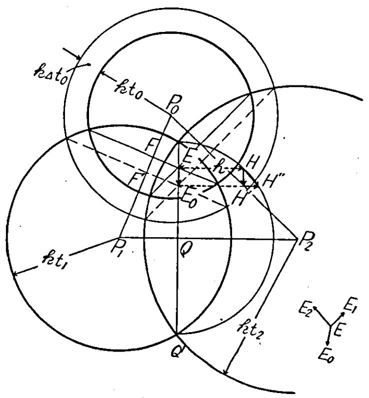

Fig. 10.

When the epicenter is determined graphically, using the duration of the preliminary tremors t_0, t_1, and t_2 of stations P_0, P_1, and P_2, circles with radius kt_0, kt_1 and kt_2 are drawn taking the centers at P_0, P_1, and P_2 respectively, and the point of intersection of the three lines that join the two parts of each of the three circles is the epicenter, as shown in Fig. 10. If we assume that the duration of the preliminary tremors at P_0 is increased by Δt_0, the epicenter E then moves to E_0, as will be seen in the figure. In this case EE_0 is always perpendicular to the base $\overline{P_1P_2}$ of the triangle, as also with respect to P_1 and P_2. Hence, the deviation in the epicentral position due to deviations in the preliminary tremors in the three stations is represented by three vectors $\overline{EE_0}$, $\overline{EE_1}$, $\overline{EE_2}$, each of which is perpendicular to the base of the triangle. When

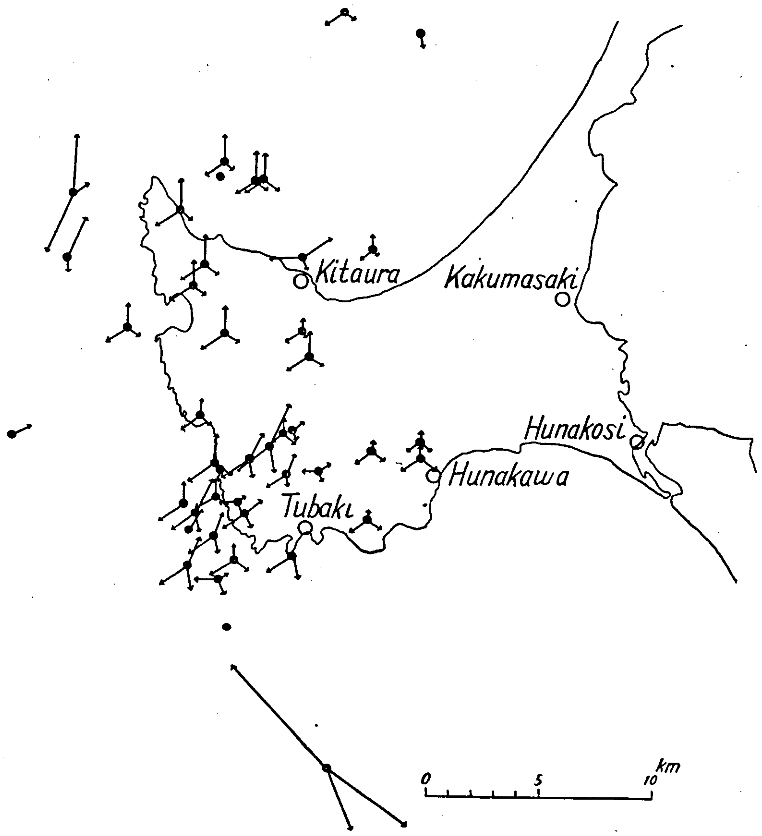

Fig. 11. Deviations in epicentral position due to a deviation 0·1 sec in the duration of the preliminary tremors.

the durations of the preliminary tremors of the three stations deviate at the same time, the deviation in the position of the epicenter is given by the resultant of these three vectors. Vector $\overline{EE_0}$ is given by the following equation when Δt_0 is sufficiently less than t_0,

$$\overline{EE_0}=\frac{k^2t_0\cdot\Delta t_0}{P_0P_1\sin\angle P_1}\left(\text{or }\frac{k^2t_0\cdot\Delta t_0}{P_0P_2\sin\angle P_2}\right). \qquad (3)$$

It will be seen from this equation that when P_1 or P_2 is small, $\overline{EE_0}$ become large, namely, when one of the angles of the triangle is too small, the effect of the errors in the duration of the preliminary tremors increases in magnitude, the same holding true for $\overline{EE_1}$ and $\overline{EE_2}$. Next, if a circle of radius QQ' is drawn with Q as its center and a line EH is drawn from E perpendicular to EQ, then length EH gives the depth of the epicenter (h). The increment in h due to increment Δt_0 is given by

$$\Delta h=\frac{\overline{EQ}.\overline{EE_0}}{h}.$$

That is, since Δh is inversely proportional to h, the deviation in depth is large when the hypocenter is shallow. The deviations in epicentral position and in depth due to a deviation 0·1 sec in the duration of the preliminary tremors are shown in Fig. 11 and 12. Actually, since the observed duration of the preliminary tremors is accurate up to 0·1 sec, such errors as are shown in the figures do not exist. In the figures, vectors are not given for shallow earthquake, because there is no solution when the duration time is increased by 0·1 sec.

It will be seen from the foregoing studies that the hypocentral distribution obtained here is accurate within about 2 km, except in the case of some earthquakes.

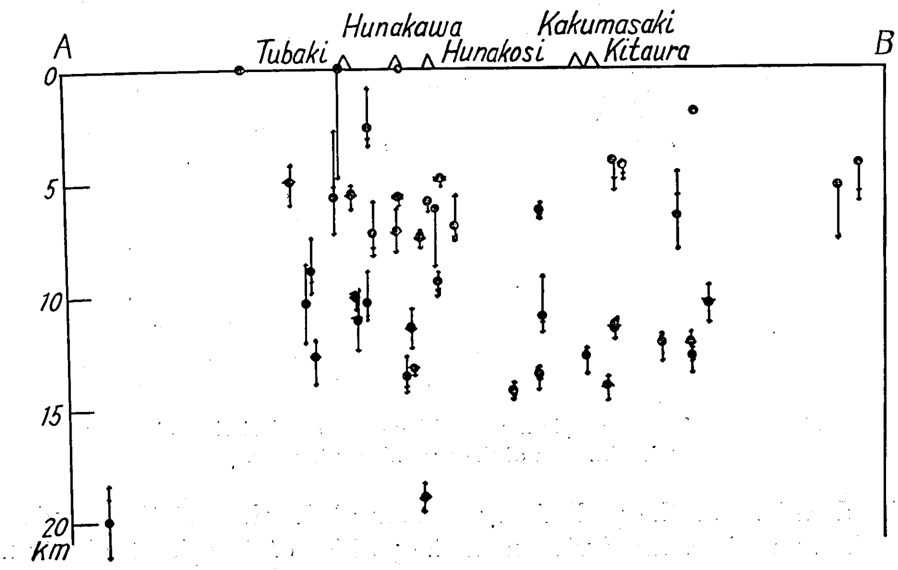

Fig. 12. Deviations in depth of hypocenter due to a deviation 0·1 sec in the duration of the preliminary tremors.

Remarks.

As will be seen in Fig. 2, the push-pull distribution of the initial motion of the first earthquake is divided into four quadrants, bordered by two nodal lines intersecting perpendicularly. The damage in the peninsula due to the earthquake was largest in that region where one of the nodal lines passes through it. It seems that since, in general, the S-phase (the principal motion) is largest on the nodal line of the P-phase, the largest damage was caused in this region.

The distribution of the aftershocks appears to be separated into two groups, north and south, which suggest that a separation of this kind is related to the fact that two severe earthquakes occurred. Moreover, the epicenters of the aftershocks lie in a quadrant where the initial motions are "push." There are two precedents in Japan wherein the epicenter of a severe earthquake and the epicenters of its aftershocks have been exactly determined, namely, the Formosa Earthquake of April 21, 1935[6], and the Earthquake of North Idu on November 26, 1930[7]. According to these investigations, the aftershocks generated in a quadrant divided by the nodal lines of the P-phase, in which the initial motion was "push"; an upheaval of the earth crust was also found in that region, as shown in Fig. 13. If we assume the same phenomenon in the present case, a more or less upheaval of ground may be expected in the western region of the peninsula. We are awaiting with keen interest the results of the triangulation in the peninsula soon to be revised by the Military Land Survey.

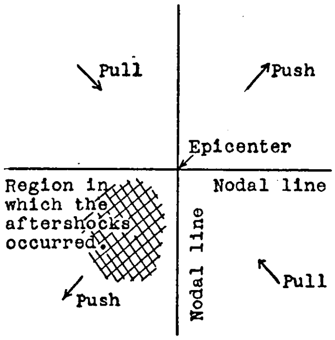

Fig. 13

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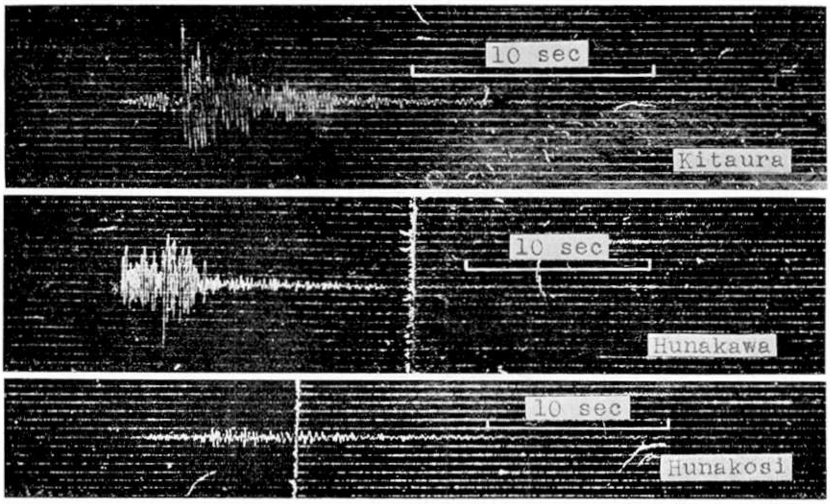
12. 昭和 14 年男鹿地震の餘震分布

地震研究所 萩原尊禮

昭和 14 年 5 月 1 日の男鹿地震直後より約 20 日間，4 臺の携帶地震計によつて，餘震觀測を行つた．其の結果，餘震は男鹿島西部に密集して居ることが知られた．震害の大であつた男鹿島東

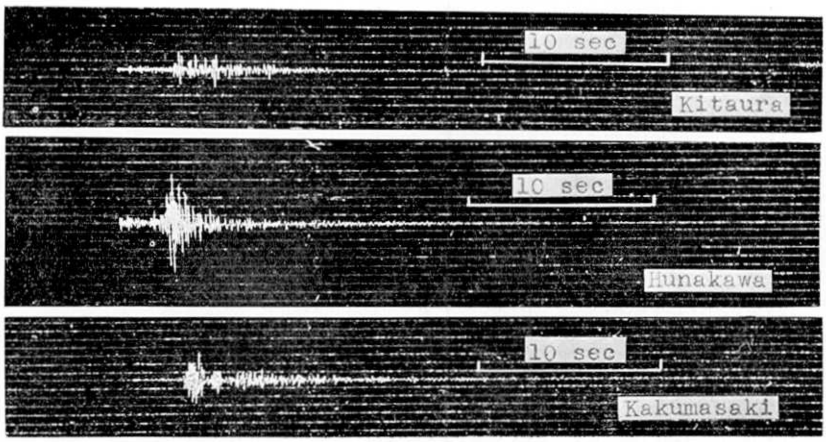
6) N. Nasu, *Bull. Earthq. Res. Inst., Suppl.* 3 (1936), 75 (in Japanese).
7) N. Nasu, *Bull. Earthq. Res. Inst.*, 9 (1931), 22.

部寒風山方面には觀測期間中は全く餘震の發生を見なかつた．本震（同程度のものが2回續いて起つたが最初に發生したもの）は男鹿島の北約 10 粁の海中と推定せられるが，これと餘震分布及び本震の初動の引き押し分布等と比較するに，去る昭和 5 年の北伊豆地震及び昭和 10 年の臺灣地震等の場合に起つたと同一の事實——餘震は初動分布に於ける押しの象限內に於て本震の隣接區域に發生すること——が見られる．從來の大地震では餘震發生區域で土地の隆起を生じたが，今回は肉眼では觀測出來なかつたけれども，近く陸地測量部によつて三角點の再測が實施されるので，或は餘震發生區域卽ち男鹿島西部に於て土地の隆起が認められるのではないかと思はれる．



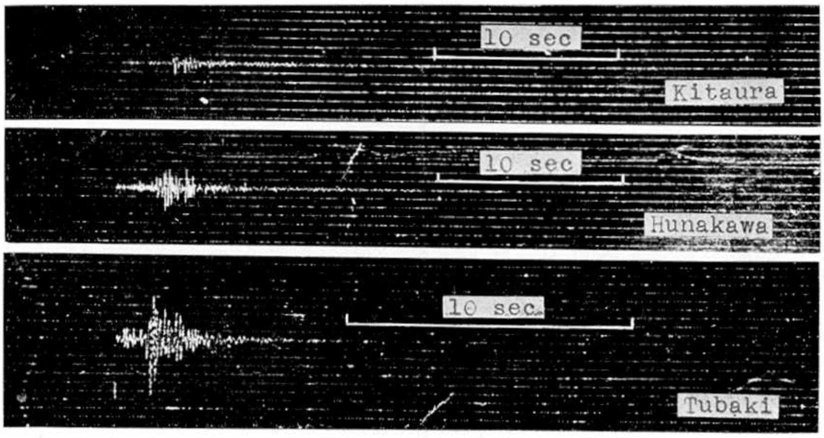
(2·4×the actual)

Fig. 14. The earthquake of 23 h 20 m, May 7, 1939.



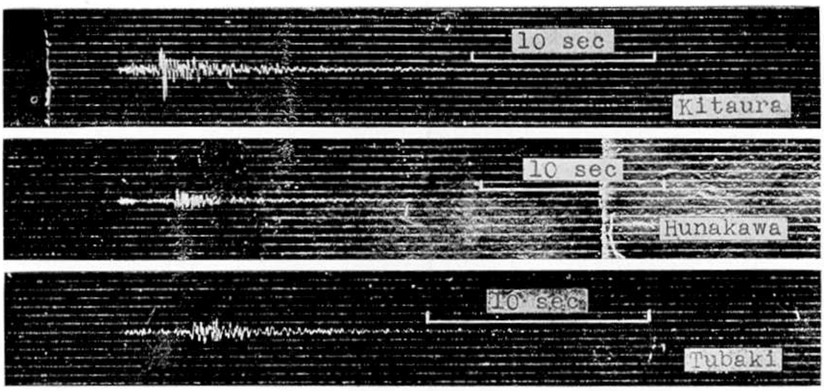
(2·4×the actual)

Fig. 15. The earthquake of 21 h 41 m, May 14, 1939.



(2·4 × the actual)

Fig. 16. The earthquake of 21 h 22 m, May 20, 1939.



(2·4 × the actual)

Fig. 17. The earthquake of 22 h 19 m, May 20, 1939.

（震研彙報 第十八號 圖版 萩原）