21. On the Aftershocks of the Fukui Earthquake. (Part 2)

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1. Introduction.

The severe Fukui earthquake which shook the Echizen Plain at 18 h 50 m on June 28, 1948, was accompanied by a great many aftershocks. The present author hurried to the seismic area with many collaborators and the observations of aftershocks were carried out by a temporary network of seismological stations from July 5 to August 10.[1] As the result of such observations it was found that the epicenters of the aftershocks were distributed all over the Echizen Plain and over the adjacent hilly regions on its east and northeast. In the course of observations we made some new attempts in recording these aftershocks: 1) With a view to knowing the exact time of the commencement of the tremors at each station, we placed time-marks on the seismograms at several stations and hoped to get time-distance curves due to the arrival times of the seismic waves of aftershocks. 2) With a view to making some studies on the distribution of the first impulsions, two horizontal motion seismometers were installed at each of the five stations. In the following two sections these two subjects will be discussed.

I. TIME-DISTANCE CURVES OF AN AFTERSHOCK.

2. The commencement times at each station.

The study of near earthquakes directed our attention to the necessity of establishing the time-distance curves in regions very near the focus of a shock. For this purpose it seemed desirable to draw time-distance curves due to aftershocks observed by a more or less small network of observation points. First it was necessary to measure the accurate commencement time of an aftershock at as many stations as possible. We selected five stations, Daishoji, Yamanaka, Shioya, Maruoka and Fukui, and on the seismograms of these stations time-marks were placed at every one minute by means of a clock and

1) S. OMOTE and others, *Rep. Fukui Earthq.* (1950 Tokyo), 37.

at every one hour by the time broadcast by radio. The time-marks in these manners of recording, however, will not give a highly accurate commencement time of a shock, but supposing a shock has happened very near the radio time-mark, the commencement time at the respective stations of such a shock will have a fairly reliable value. Fortunately enough we had such a shock, and it was recorded at all the five observation stations though it was the only case out of the 500 recorded aftershocks to satisfy this condition. This shock took place at about 16 h 01 m of July 29 and had the intensity I due to the Japanese scale at the nearest station, Daishoji. Seismograms obtained at the respective station are reproduced in the Plate. The position of the epicenter of this shock, reported on in the previous paper, is shown in Fig. 1 by a double circle. The commencement time of this shock was recorded at the respective stations as listed in the last column of Table I. Since, with respect to this table, the accuracy of the figures in the last cloumn concerns us most, the processes by which these figures were derived and the probable errors in the materials used are given

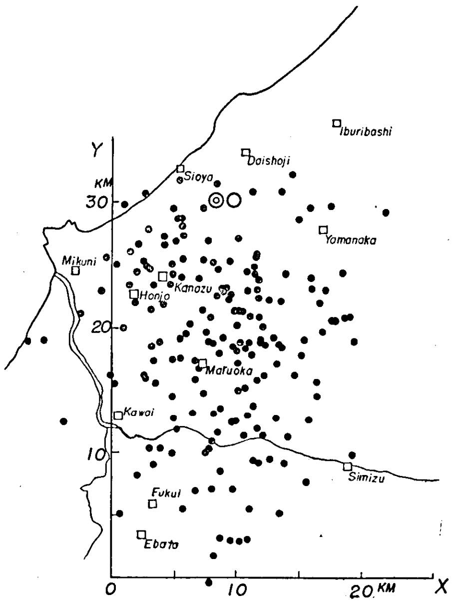


Fig. 1. Distribution of foci of aftershocks.
◎; epicenter of the shock determined in the previous report.
○; revised epicenter.

Table I. Commencement times at observation stations.

	Length of one minute mark	Time of two marks	AB	RB	BP	Commencement time		P	S
	mm mm	sec	mm	mm		h	m	sec	sec
Daishoji	73·0±0·064	59·91	73·3	64·4	10·5	16	01	2·78	4·89
Shioya	60·4±0·063	60·37	60·89	0·18	2·3	16	01	2·79	4·90
Maruoka	63·5±0·051	60·42	63·9	7·8	59·0	16	01	3·61	6·28
Yamanaka	63·3±0·054	60·08	60·1	26·5	37·1	16	01	2·96	5·22
Fukui	26·9±0·054	—	—	—	10·1	16	01	5·56	9·57

in preceding columns in the same table. The notations in Table I refer to the corresponding letters in Fig. 2. As shown in the table the shock occurred in less than 61 seconds after the radio time mark of 16 h 00 m, so that the accuracy of the commencement time observed at the stations will be trusted to within ± 1.0 second, and further, considering that the revolution of the recording drums was not very irregular at that time, the commencement times will be

Fig. 2. An example of a seismograph with time marks. R is radio mark A, B and C are minute marks.

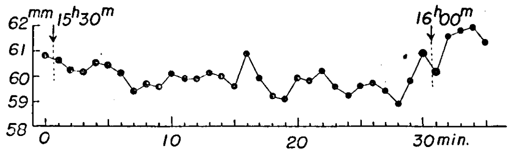


Fig. 3. Variation of the length of time mark of every one minute at Shioya station.

accurate even to ± 0.1 sec. The length of the record between two successive minute-marks observed at Shioya Station is plotted and shown in Fig. 3 as an example. From this figure we shall be able to infer the degree of uniformity of the revolution of the recording drum and the accuracy of the minute marks of the clock.

3. Determination of the focus.

In order to determine the focus of this shock three different methods were applied.

i) The focus of the shock calculated from the times of arrival of waves.

The orthogonal co-ordinates X, Y were placed in the positions shown in Fig. 1, and Z was taken vertically downward with its origin at the earth's surface. Now take the co-ordinates of the focus as X, Y, Z, the origin time of the shock as T_0, and the velocity of P and S waves as V and v respectively. Though the velocity distributions within the earth are not yet known, for the sake of simplicity, we assumed that P and S waves were uniform in velocity throughout the whole area, and that the wave paths were straight lines from focus to station. These assumptions, to be sure, may not be strictly applicable, but some evidences seem to indicate that the granitic layer exists very near the earth's surface and the depth of focus is not over 15 km, so that it may be safe to assume a uniform velocity and a straight path of seismic waves. As discussed in the previous paper the value of the Omori constant k was calculated as $k=7.2$. With the earthquakes in regions along the Sea of Japan, k always has a large value, and it appears probable that in these regions the uppermost layer which Matuzawa[1] found in the Kwanto District

1) T. MATUZAWA, *Bull. Earthq. Res. Inst.*, 7 (1329), 241.

is supposedly very thin if it exists at all, and the second layer (granitic layer) stretches very near the thin superficial sedimentary layer. In this way we have five unknown quantities and five observed values due to five stations, and these unknown quantities will be solved easily as follows:

X=9.59km, Y=28.65 km, Z=1.40 km, T=16 h 01 m 1.83 sec., V=6.33 km/sec.

ii) The focus of the shock calculated from the commencement times of S waves.

If we make the same assumptions with S waves as with P waves, the observed value of the arrival time of S waves will allow us to calculate the co-ordinates X, Y and Z of the focus, the origin time t_0 and the velocity v of S waves. The results of calculation will be as follows:

X=9.53 km, Y=29.00 km, Z=5.03 km, t_0=16 h 01 m 2.75 sec., v=3.58 km/sec.

iii) The focus of the shock calculated from P–S times.

P–S times (duration time of preliminary tremor) at the respective stations are easily known from the commencement times of P and S waves observed by them, and from these P–S times the focus and the Omori constant k will be calculated. The result obtained in this way is as follows:—

X=9.57 km, Y=29.77 km, Z=14.21 km, k=7.15.

If we compare the values obtained in i), ii) and iii) with each other we at once see the close proximity of the figures of the co-ordinates X, Y of the epicenter. These two values, therefore, are certainly reliable, but the other values derived above have such unreasonable figures that our next question is how to find out the most reasonable values for the position of the focus, the origin time and the velocities of P and S waves.

4. The focus of the shock.

First of all we will concentrate our attention on the determination of the position of the epicenter of the shock. For that purpose we will begin by assuming that

V=5.1 km/sec., T_0=0.16 sec.,

in this, V is the velocity of the P waves and T_0 is the value wich will satisfy

16 h 01 m+T_0=origin time of waves

then the focus will by the least square method, be:—

$X=9.83\pm0.907$ km,

$Y=29.67\pm0.145$ km,

$Z=12.30\pm0.065$ km,

Taking these as the first approximation values, the correction values were calculated as:—

$\delta X=+0.053$ km, $\delta Y=-0.201$ km, $\delta Z=+0.086$ km.

With respect to S waves, in the same way as with P, the velocity and origin time of S waves will be assumed to be:—

$v=3.0$ km/sec., $t_0=-0.11$ sec.,

then the focus will be:—

$X=9.79\pm0.090$ km,

$Y=30.02\pm0.043$ km,

$Z=13.45\pm0.020$ km,

and the correction terms:—

$\delta X=+0.058$ km, $\delta Y=-0.135$ km, $\delta Z=+0.051$ km.

As to the P–S time, we assume $k=7.4$, whence:

$X=9.87\pm0.792$ km,

$Y=30.52\pm0.375$ km,

$Z=14.98\pm0.168$ km,

$\delta X=-0.18$ km, $\delta Y=-0.71$ km, $\delta Z=-0.11$ km.

5. Determination of the velocities and origin times of P and S waves.

Besides the notations used in the preceding paragraphs, we introduce here d_i, P_i and S_i, where d_i being the distance from the focus to the station i, P_i and S_i being the commencement times of P and S waves at the station i. We then have[1]:—

for P waves: $d_i/V+T_0=P_i$, $i=1, 2, 3, 4, 5$.

for S waves: $d_i/v + t_0= S_i$, $i=1, 2, 3, 4, 5$.

The two groups of unknowns $(1/V, T_0)$ and $(1/v, t_0)$ can be solved severally by the least square method from the above two pairs of equations, and we get:—

$V=5.071\pm0.002$ km/sec., $T=+0.061\pm0.038$ sec,

and $v=3.015\pm0.003$ km/sec., $t_0=+0.321\pm0.054$ sec.

According to this result the time of origin of S waves seems to have been a little later than that of P waves, but it will still be too rash to discuss from this result the problem which waves, P or S, were generated first.

6. Residuals.

The focus of the shock, the time of origin and the velocities of P and S waves have all been measured by the above calculations. And therefore, if we assume that a seismic wave had started from the focus thus determined at the time corresponding to the origin time of P or S wave and spread with

1) P. G Gane, A. L Hales & H. O. Oliver, *Bull. Seis. Soc. Amer.*, 36 (1946), 49.

the velocity of P or S thus determined, we shall be able to calculate the arrival times of P and S waves at each station. The difference between the two arrival times, the observed and the calculated, at the respective stations will be seen in the A and C columns in Table II.

This difference is less than 0.2 seconds at any observation station with respect to both P and S waves. If we shift the origin time of P or S wave slightly, namely 0.10 sec. for P and −0.17 sec. for S, the values of the residuals will become fairly small. (See B and D columns in Table II). On the whole

Table II: Residuals of observed minus calculated origin time.

Station	P		S		P∼S	
	A	B	C	D	E	F
	$ti-t$ cal	$ti-t$ cal	$ti-t$ cal	$ti-t$ cal	$(P\sim S)_{ob}$	$(P\sim S)_{cal}$
	$T_0=0.06$	$T_0=0.16$	$t_0=0.32$	$t_0=0.15$	I*	II*
Daishoji	+0.13	+0.03	−0.09	+0.08	+0.04	−0.04
Shioya	+0.06	−0.04	−0.21	−0.04	−0.02	−0.13
Yamanaka	+0.08	−0.02	−0.19	−0.02	0.00	0.00
Maruoka	+0.12	+0.02	−0.18	−0.01	−0.03	−0.03
Fukui	+0.09	−0.01	−0.16	+0.01	+0.01	−0.02

* I; forcus is assumed at $X=9.87$, $Y=30.52$, $Z=14.93$ and II at $X=10.84$, $Y=29.81$, $Z=15.47$.

these are very satisfactory results, but closer examination of the Table reveals that residuals at Maruoka and Fukui stations are somewhat larger than those of the other stations. This may indicate the existence of a thicker layer of alluvium underneath these regions, but the amount of the residuals is so small that it will be of little use if we are to calculate the thickness of the alluvium from these data.

7. Time-distance curves.

The results obtained in this Section will be summarized as follows:—

The focus of the shock: $X=9.81$ km, $Y=29.72$ km, $Z=13.79$ km,

The origin time: $T_0=16$ h 01 m 0.06 sec, $t_0=16$ h 01 m 0.32 sec.

Velocities: $V=5.07$ km/sec, $v=3.02$ km/sec.

The arrival times of P and S waves plotted with reference to their respective epicentral distances determined from the above results are shown in Fig. 4. Incidentally, the time-distance curve due to hypocentral distance is given in Fig. 5.

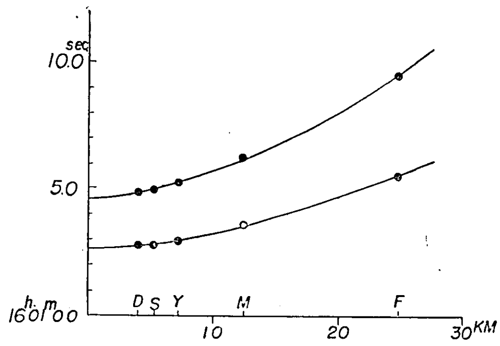


Fig. 4. Time distance curves. D, Daishoji; S, Shioya; Y, Yamanaka; M, Maruoka; F, Fukui.

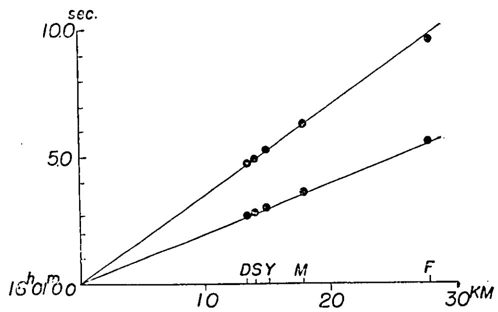


Fig. 5. Commencement times of P and S waves plotted to the hypocentral distances. D, Daishoji; S, Shioya; Y, Yamanaka; M, Maruoka; F, Fukui.

II. DISTRIBUTION OF THE FIRST IMPULSIONS OF AFTERSHOCKS.

8. Observation of the first impulsions.

The observation of aftershocks was carried out at eleven stations. Of these eleven stations five were equipped with two horizontal motion seismometers to conduct the study of the first impulsions of aftershocks. These five were stations at Fukui, Ebata, Maruoka, Shioya and Daishoji, and at the last named (Daishoji) station a vertical motion seismograph was also installed. The records obtained at Fukui were not suitable for the study, the beginning of the motion not being clear enough in them, and the observation at Ebata station covered only a too brief period. It will be seen, then, that the number of observation points was too small to draw a distribution map of the first impulsions with respect to each individual aftershock.

9. The distribution map of the first impulsions.

As the first step to this study we assumed that all the aftershocks took place with the same mechanism and at the same depth. Next, we put the epicenter of an aftershock upon that of another, in this way piling up the epicenters of all the shocks at a single point in the map. We then drew an arrow at the spot corresponding to each observation point to indicate the direction of the first impulsion.

Such a map is the result of the observation of many aftershocks at one seismic station (the epicenters of the aftershocks being determined by the three- or four- station method), and consequently the meaning of this map is that:—It gives a diagram showing the distribution of the first impulsions of a seismic wave when an imaginary shock took place at the origin point in the map and obsevations of the first impulsion were carried out at all the points denoted by full or open circles in the map.

Fig. 6 is a map obtained from Daishoji station and Fig. 7 from Maruoka station. From these we at once notice that the above assumptions do not

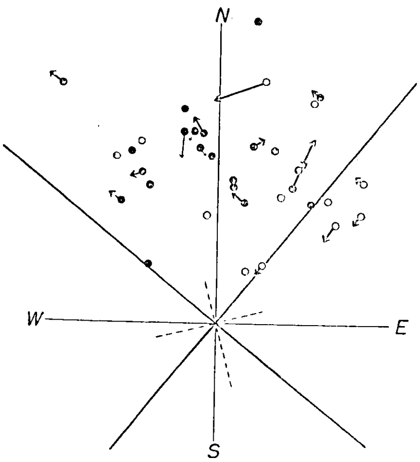


Fig. 6. Pull push distributions due to the Daishoji station. ●; push, ○; pull.

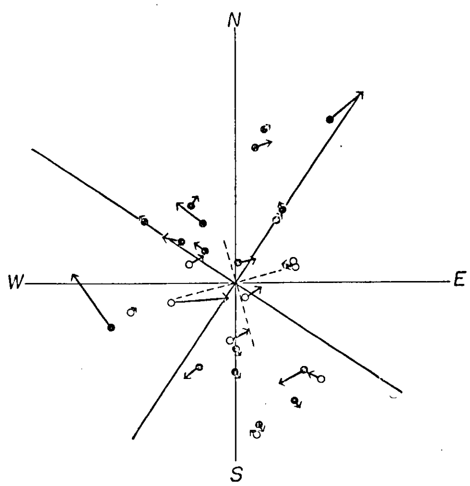
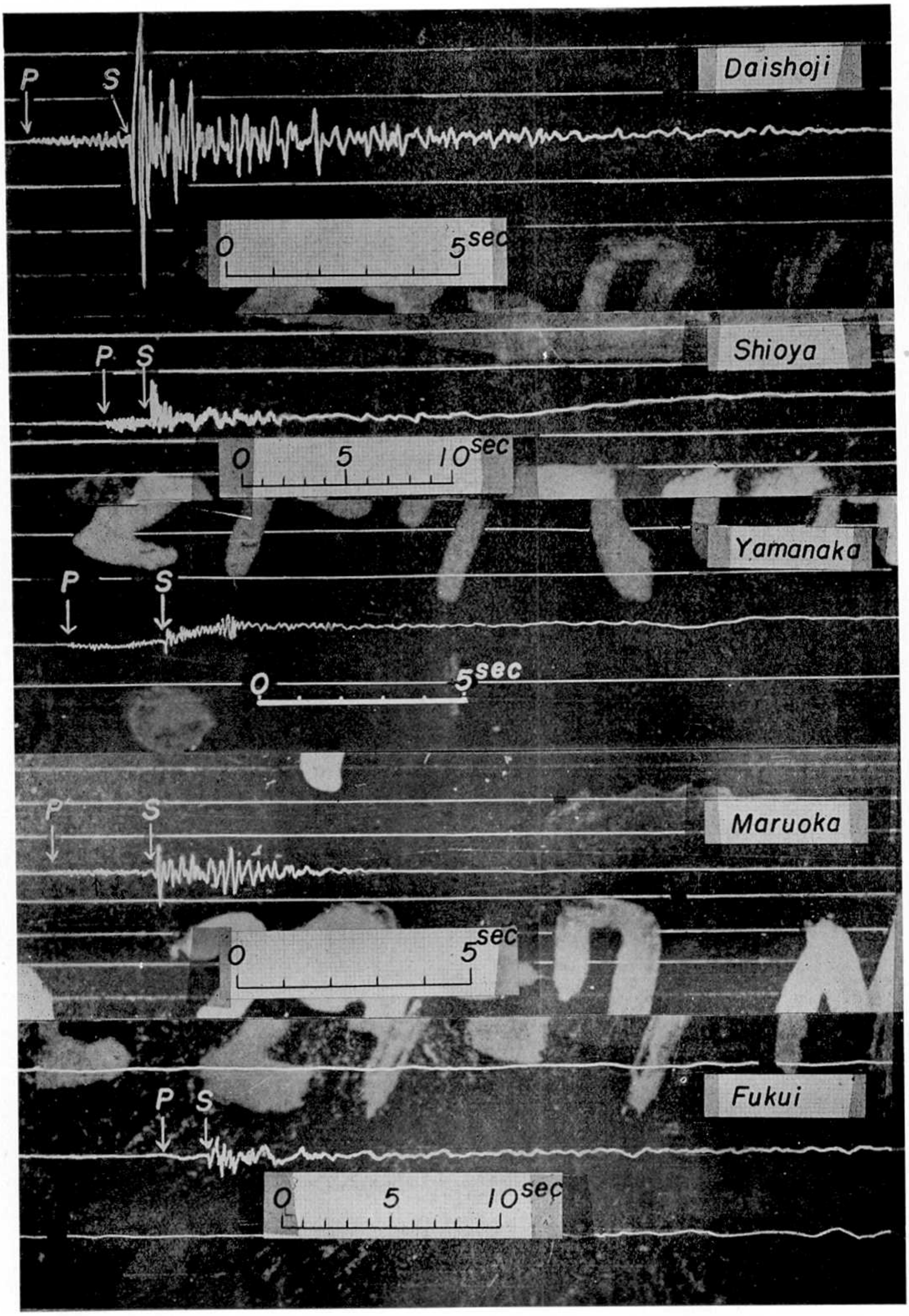


Fig. 7. Pull push distributions due to the Maruoka station. ●; push, ○; pull.

apply wholly well in these cases, but still, if we except some few shocks (shown by arrows in thin lines), we can see that the majority of the aftershocks are to be considered to have had the same mechanism of occurrence. The regions of the first condensation and rarefaction are to be divided into four quadrants.

The distribution of the first impulsions of the main shock was studied by


Daishoji
P
S
0
5sec
Shioya
P
S
0
5
10sec
Yamanaka
P
S
0
5sec
Maruoka
P
S
0
5sec
Fukui
P
S
0
5
10sec

T. Hirono[1], who drew the two nodal lines intersecting each other at a right angle at a point near the epicenter of the main shock, one of them having the direction of $N\ 20°\ W$. According to the results here obtained by us the direction of the nodal lines due about 35 degrees counter-clockwise.

At Daishoji station a vertical motion seismograph had also been installed. If we examine Fig. 6 minutely we notice that with respect to three shocks observed at Daishoji the direction of the first impulsion determined from the two components of horizontal motion seismometers contradicts with the direction derived from the vertical motion seismometer.

This fact brings forward a serious problem to the study of the first impulsions. It cannot be denied that some unsatisfactory records of small amplitudes of aftershock had to be used in this study of the first impulsions, and that more strict examinations of these records are needed before accuracy of results is to be hoped for.

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21. 福井地震の余震について

地震研究所 表 俊 一 郎

昭和23年6月28日の福地震の余震の震央分布については既に別に報告されてゐる．この福井地震の余震観測の際余震の發震時を求めるための試みがなされ幸にして1つの余震については可なりの程度迄信用し得る發震時を測定し得たので，種々の方法によりその余震の震央を求めた．その結果P, Sの發震時から獨立に求められた震央も略々一致した價となること，P, Sの震源での發震時も略々同一の値となり，特にどちらかがたしかに早く震源を出發したと主張出來るやうな證據は認められなかつたことが注意された．P及びSの速度V及びvは夫々$V=5.2$ km/s, $v=3.0$ km/sとなり沖積層の下にすぐ所謂 granitic layer が來てゐるのではないかと思はせるものがあつた．各觀測點の發震時と，最後に求められた震央及 origin time 及び速度より計算によつて得られるP, Sの到達時刻との差から沖積層の厚さを求めようとしたが上述の差があまり小さくなつたために之は求め得なかつた．震央距離25 kmまでの發震時による走時曲線を圖に示した．次に余震の押引の分布を求めた結果本震の押引の分布とくらべ節線の位置が反時計的に35°回轉したと考へられるやうな分布を示すもののやうである．

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1) H. KAWASUMI and others, *Rep. Fukui Earthq.* (1950, Tokyo), 6.