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Investigation of Microearthquakes in Kinki District
—Seismicity and mechanism of their occurrence—

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Abstract

Observation of microearthquakes in the western part of Kinki District has been carried out at 5 stations attached to the Tottori Microearthquake Observatory. Epicenters of about 200 earthquakes for ten months since Angust, 1964 were determined, giving a particular pattern of distribution. The areas in which the earthquakes occur frequently are separated in a complicated but nevertheless sharp manner from the areas where earthquakes seldom occur.

Magnitude of these earthquakes was distributed from -1 up to more than 4.

The distribution of direction of the first P motion shows a definite pattern for almost all earthquakes. This pattern coincides well with that of earthquakes with larger magnitude in this district.

Introduction :

We have been advancing since 1963, the construction of the microearthquake net-work to conduct research into their natures and seismicity. Now we have five stations and the data recorded at those stations has now amounted to fairly large amount.

We intended to make a report in a little more detail after the preliminary report.[1] The outlines of observation stations attached to Tottori Microearthquake Observatory are shown in Table 1. The net-work covers the northern Kinki district with nearly 30 km to 40 km span. The observation system is

TABLE 1.
Outline of observation stations attached to Tottori microearthquake observatory.

	Mikazuki	Funaoka	Oya	Hikami	Izumi
Abrevation	Mz	Fo	Oy	Hm	Iz
Latitude (E)	34°59′01.3″	35°19′59.3″	35°20′02.0″	35°13′35.5″	34°58′20.0″
Longitude (N)	134 26 44.6	134 16 18.4	134 39 52.2	135 02 36.6	134 53 15.5
Height (m)	200	160	260	250	230
Lat. (km)	0	38.768	38.831	26.940	− 1.272
Long. (km)	0	−15.851	19.932	54.507	40.351
Components	1V 2H	1V	1V 2H	1V	1V
Sensitivity	400μkine/cm	400μkine/cm	400μkine/cm	400μkine/cm	400μkine/cm

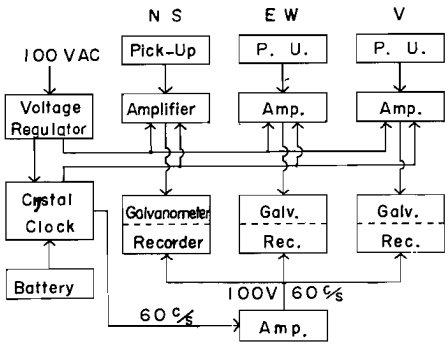


Fig. 1. Blockdiagram of observation system.

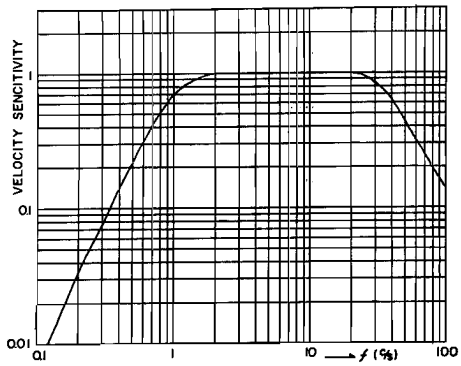


Fig. 2. Overall frequency response.

illustrated as a block diagram in Fig 1. The figure shows the recording system from the output of seismometer with 1 sec natural period, through electronic amplifier, to drum recorder with ink writing pen galvanometer. A X'tal clock for time mark is corrected once a day by Japanease Standard Time (J. S. T.) and it is always kept in the accuracy of 0.01 sec. Sensitivity is kept at 400 μkine/cm for each station and component. Paper speed is 4 mm/s. Frequency response curve for the allover system is as shown in Fig. 2. In this paper we shall discuss the seismicity, earthquake mechanism and some problems related to them.

Outline of seismicity:

First of all we sum up in Table 2 the number of earthquakes observed at those stations for each month from 1964 Aug. to 1965 June. Here the data are confined to earthquakes of which the maximum velocity amplitude is greater than 40 μkine and the P-S time is less than 15 sec. This figure does not necessarily represent the true seismicity because of a little difference or change of sensitivity, the difference of observation components, interuption of observation for a short time (interuption for a long time is corrected proportionally) and so on. But at Mikazuki the earthquakes observed were comparatively many and at Funaoka less earthquakes were observed. As for variation of seismicity,

TABLE 2.
Number of earthquakes observed at five stations for each month from 1964 Aug. to 1965 June.

St.	1964 Aug.	Sep.	Oct.	Nov.	Dec.	1965 Jan.	Feb.	Mar.	Apr.	May.	Jun.
Mz	80	225	154	108	64	101	80	92	80	193	222
Fo	41	51	33	44	47	57	35	34	43	42	78
Hm	119	76	87	65	64	87	/	/	30	57	265
Oy	/	/	/	61	50	67	28	88	72	47	107

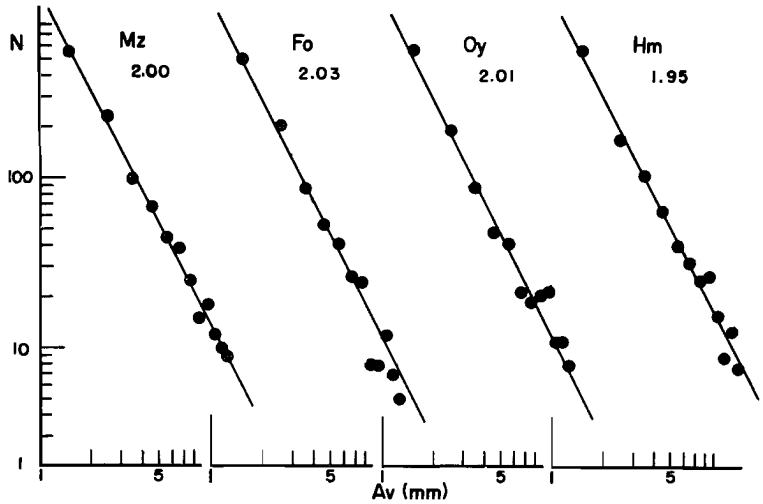


Fig. 3. Relations between the number of earthquakes and muximum amplitude.

however, we must continue the observations for a longer period. In June, 1965, a comparatively large number of earthquakes were observed but they were mainly due to a earthquake swarm occurring at the northwestern part of Hyogo Pref.

Then we investigated the so called Ishimoto-Iida's coefficient 'm' in equation (1) and show the result in Fig. 3.

$$N(A)=kA^{-m} \qquad \cdots\cdots\cdots\cdots\cdots\cdots (1)$$

A : maximum trace amplitude,
N : number of earthquakes,
k : constant.

The value of 'm' is said to be about 1.9 to the tectonically caused earthquakes.[2] In this district the value is nearly 2.0 and a signficant difference between respective stations could not be seen so far as this stage is concerned.

As for the same kind of statistics, Miyamura, for example, studied the so called Gutenberg-Richter's coefficient 'b' in equation (2) using the data obtained by the net-work of the Japan Meteorological Agency (J.M.A.).

$$\log N=a+b\ (8-M) \qquad \cdots\cdots\cdots\cdots\cdots\cdots (2)$$

M: magnitude,
N: number of earthquakes,
a: constant.

He said that 'b' differs for the various stages of tectonic movement, and in our district it is about 0.7.[3]

To know the difference between the stations in datail, we must deal with separately the earthquakes in each small region over a longer period.

Distribution of hypocenters :

We determined epicenters of about 200 examples of which the P-S times were within 15 sec and both initial P and S phases were recorded clearly at more than three stations. These earthquakes make up about 20% of the total earthquakes observed in our net-work. As for focal depth only about 60 earthquakes could be determined because the data was selected more strictly than in the case of epicenter. Hypocenters were determined as follows.

Adopting the suitable crustal structure for this district and assuming Poisson's ratio to be $\sigma=1/4$, we determined graphycally the most fitting situations of hypocenters using P-S time. The crustal structure was determined by the Research Group for Explosion Seismology (R. G. E. S.) by Kurayoshi-Hanabusa explosions, who presented two models, Model I and Model II,[4] and we tentatively used Model II. The results would not be affected greatly by the difference of the models in determing hypocenters because in this case deep earthquakes did not be found out where the difference is great between two models.

The accuracy is about 2~3 km for epicenters and about 5 km for focal depth in average epicentral distance and magnitude. Concerning the method of determining hypocenters an improved one is now being investigated by the authors. The result is shown in Fig. 4 and Fig. 5 for the distribution of epicenter and focal depth respectively. In Fig. 5 the frequency distribution is weighted by reciprocal accuracy for each earthquakes.

One can find the following features in these figures, although the earthquakes were not picked up equally over the long epicentral distance due to the attenuation of seismic energy. Some aseismic zones seem to exist, namely,

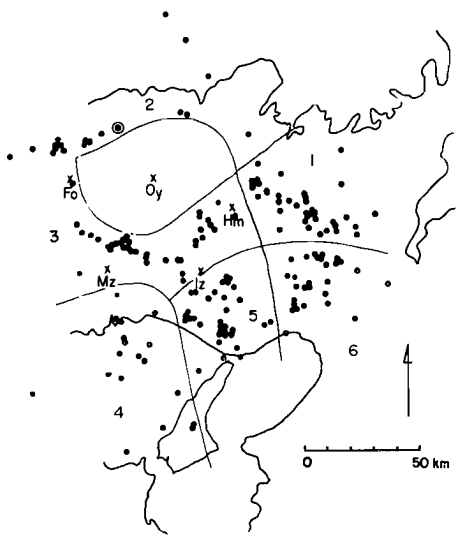


Fig. 4. Distribution of epicenters.
× : ofservation stations,
● : epicenters,
⊙ : earthquake swarm at June 1964.

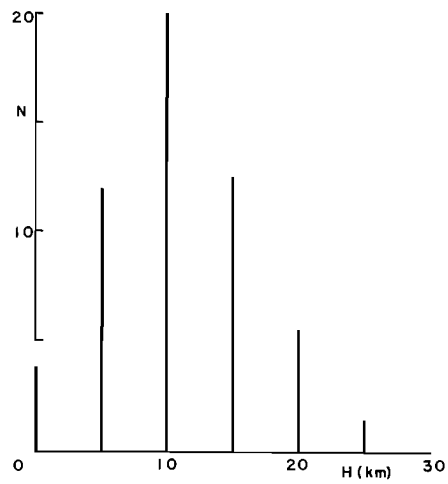


Fig. 5. Distribution of focal depth.
H : focal depth in km,
N : frequency in number.

1. The region of the radius of 25 km around Oya,
2. Most western part of Hyogo Pref.,
3. Around the region of Tamba-Sasayama, Hyogo Pref..

As for the regions of high seismicity they are tentatively divided into six regions referring to geological knowledges and for the convenience of study.

1. Tamba belt,
2. San'in district,
3. Around Oya,
4. Seto inland sea,
5. Rokko mountains,
6. Yodo river zone.

As a whole, northern part of Kinki is thought to be a transient zone from the highly seismic region of the eastern part to the low-seismic region of the western part. The focal depth is very shallow, concentrating mainly at 10 km and no earthquakes deeper than 30 km were found.

In Fig. 4 ◉ mark is a earthquake swarm occuring in June, 1964. The hypocenters of 63 earthquakes were determined and they were considered to occur in a very small domain at the depth of 15 km with nearly the same mechanism. Earthquake swarms of a similar kind but on a much smaller scale have been observed here and there in this district. It is an interesting problem to know how those small earthquake swarms occur and whether they systematically develop to the great earthquake swarms or not.

Now some questions are left as to whether or not the above illustrated distribution which was obtained from earthquakes of a limited number represents the actual earthquake activity.

However, reflecting the P-S time distribution for each stations shown in Fig. 6, in which the earthquake swarm in June, 1964 was omitted as it may not represent the stationary tendency, this figure seems to correspond well to Fig. 4. For instance, P-S time of less than 2 sec can rarely be found at Oya, which coincides very well with an aseismic zone around Oya, and some frequency peaks are explained well by the previous seismicity map in Fig. 4.

At Mikazuki, a peak of P-S time of 13 sec corresponds to the earthquakes near Wakayama City, occurring frequently and at other stations also this

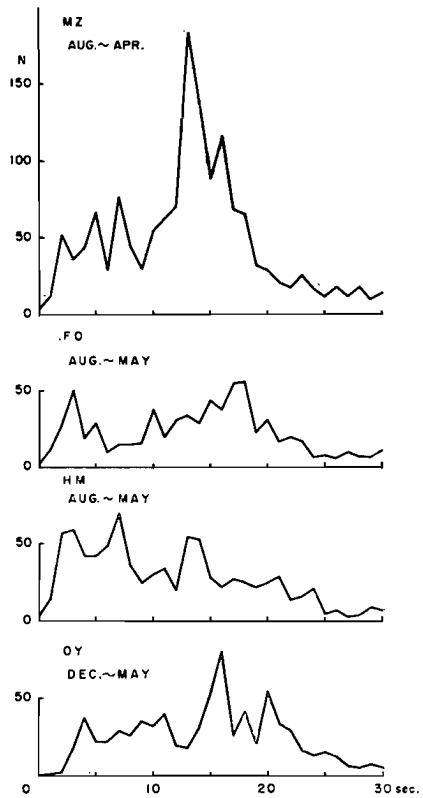


Fig. 6. P-S time distribution for each station.

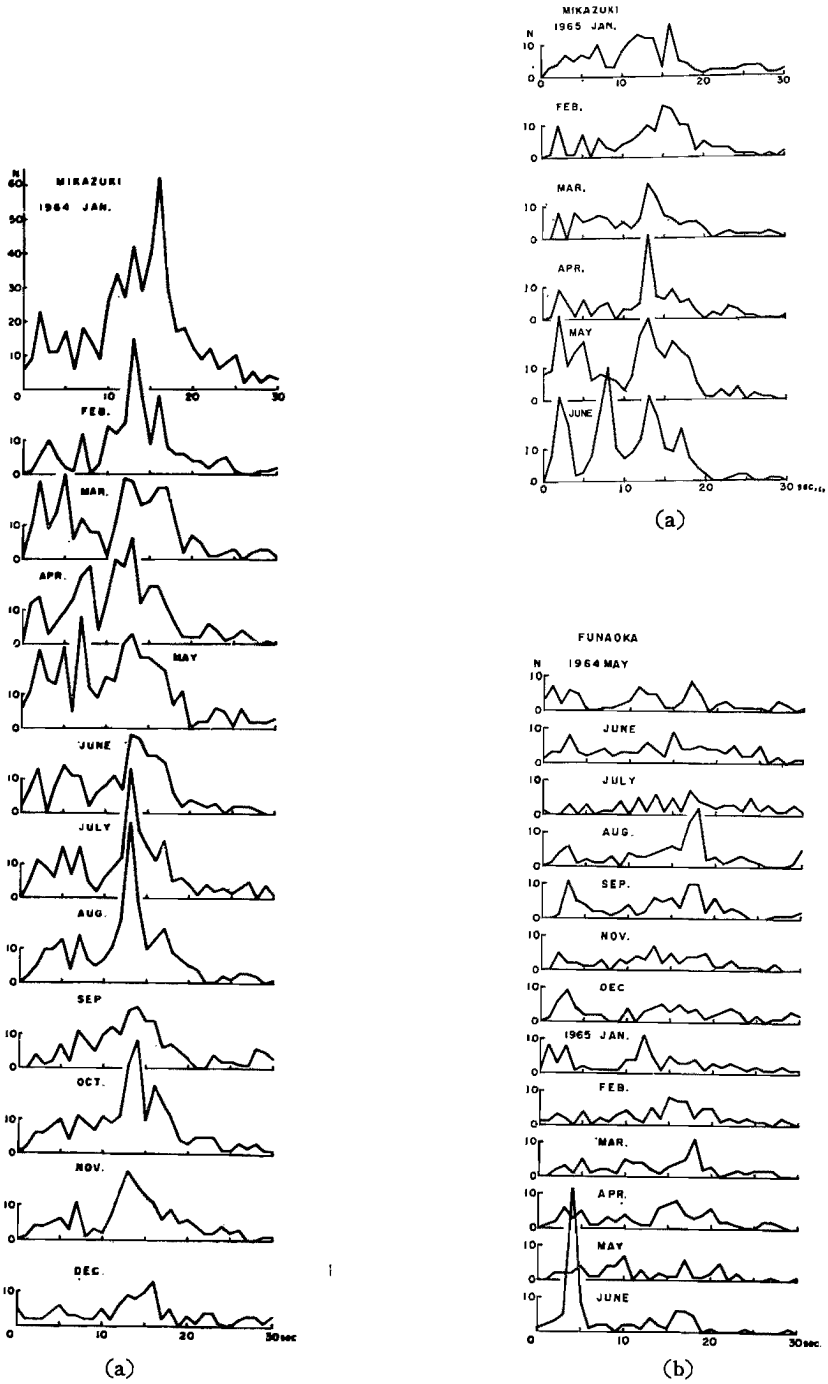
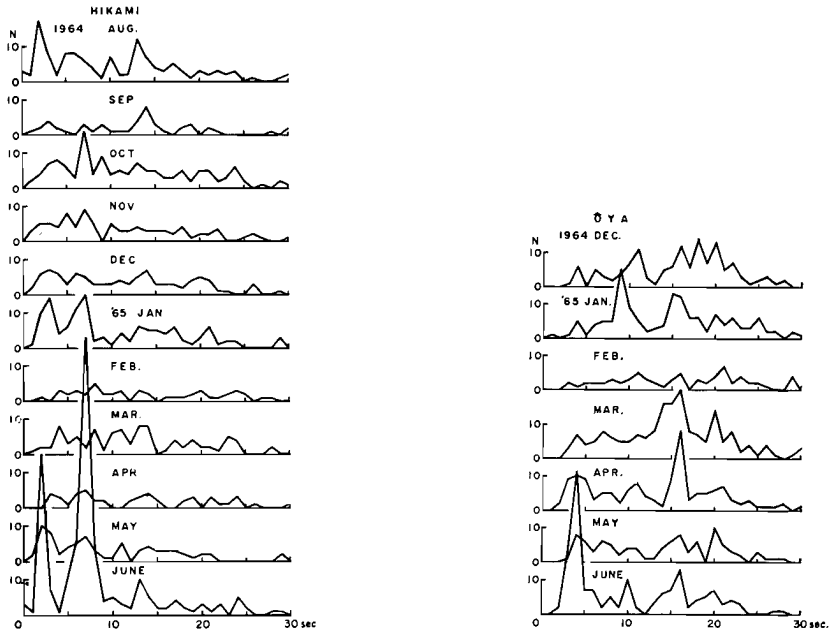


Fig. 7. P-S time distribution for each month.



(c) (d)

Fig. 7. P-S time distribution for each month.

peak is observable at respective P-S time.

In Fig. 7, P-S time distribution for each month is shown. The peaks vary from month to month but as a whole great change of seismic activity can not be seen.

Magnitude :

Then we determined the magnitude of which epicenters were known. The method is after Muramatsu who extended and improved the formula of Magnitude given by Tsuboi for the microearthquakes, studying the microearthquakes in Gifu Pref.[5]

In this study he said the maximum velocity amplitude decayed exponentially to the epicentral distance. In Fig. 8 some of the attenuation curves are shown for each region above-mentioned. In this figure the maximum velocity amplitude is estimated from the vertical component.

Sensitivity was regulated fairly well and the irregularities of attenuation curves would be largely owing to other causes such as the difference of phase, crustal structure, local effects and earthquake mechanism. Irregularity is great especially in the Rokko mountains. Earthquake magnitude distribution is shown in Fig. 9 except for the earthquakes for which we were not able to determine the magnitude by this method. Trying to get the coefficient of Gutemberg-Richter's 'b', the coefficient became rather small compared to that of large earthquakes. This fact would only show the difficulty of determination of microearthquake magnitude, althought it is very neccessary to deter-

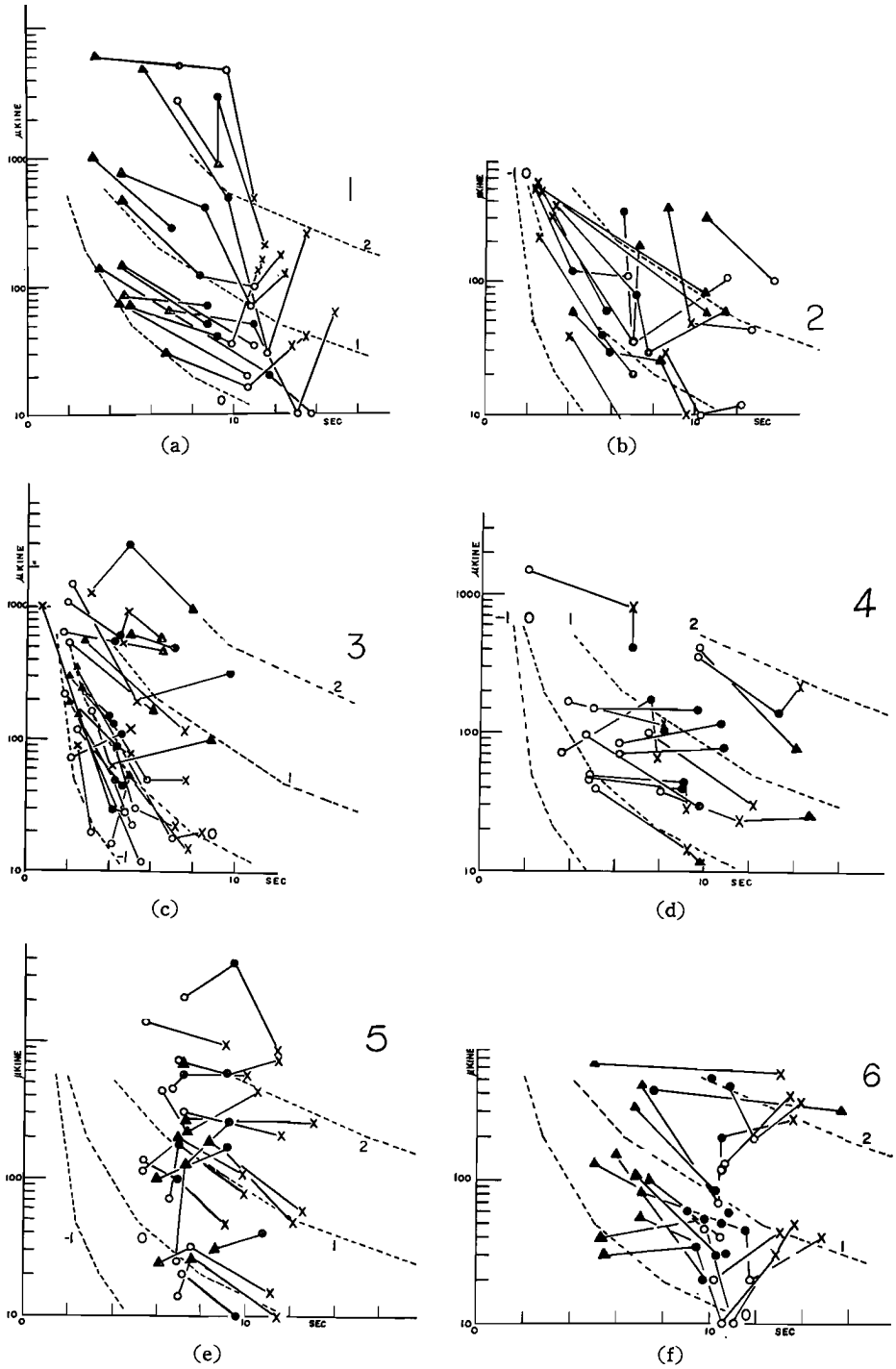


Fig. 8. Attenuation curve for each region.

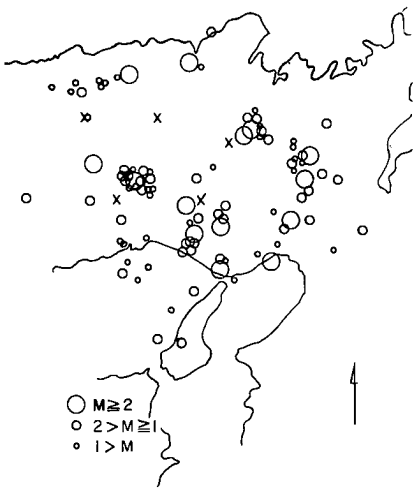


Fig. 9. Earthquake distribution with magnitude.

mine the magnitude correctly enough to get the relation between the microearthquakes and the large earthquakes accompanied by great damage.

The mechanism of earthquakes :

The mechanism of earthquakes has been studied by many seismologists, theoretically and observationally. And various models of earthquake mechanism are generally proposed.[6]

One of them is called "type I", which is represented by a single couple, namely two equal and opposite forces with a moment which act at a point. The other, "type II", is a force system of double couples, perpendicular to each other, which also act at a point. The source of slipping fault plane is explained by the integration of the force system "type II"[7]. On the other hand, another model called "cone type" is proposed in some cases.

The sources of both "type I" and "type II" give the same quadrant distribution of first P motion. Those two types of force system can be distinguished by investigating the distribution of the first S waves. From the observational standpoint these models of mechanism were given mainly by earthquakes of comparatively large magnitude. It is also well known that the mechanisms of earthquakes in the same region are frequently similar to each other, which is supposed to suggest that these earthquakes might be caused by the same stress acting around the region. But little is known about the mechanism of microearthquakes because of the lack of sufficient data over a wide area, although it is considered to be very important to clarify the mechanism of earthquakes.

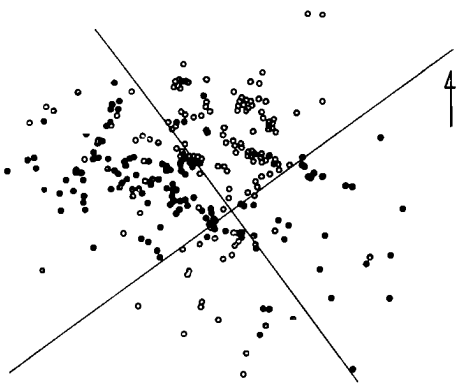


Fig. 10. Distribution of first P motion around epicenters.
○ : push, ● : pull.

Then we summed up the distribution of first P motions around those epicenters as a origin[8]. Here first P motions are confined to only very clear phases. The summed up result of all the earthquakes seems to have a definite pattern except for a few earthquakes and can be divided into quadrants by two nodal lines perpendicular to each other, as shown in Fig. 10. In this figure ○ and ● indicate the first P of push (or outward) and pull (or inward) motions,

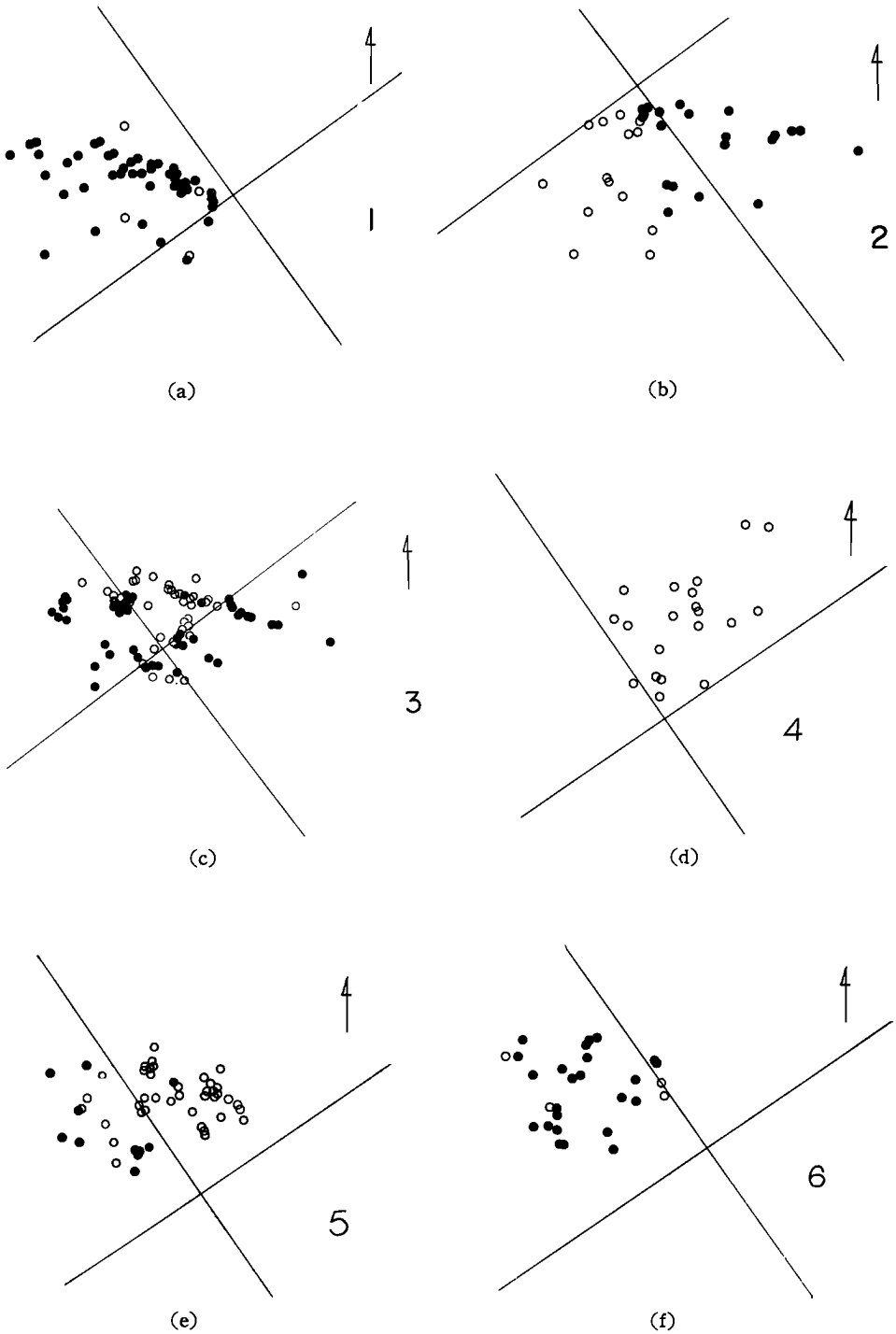


Fig. 11. Distribution of first P motion for each region.

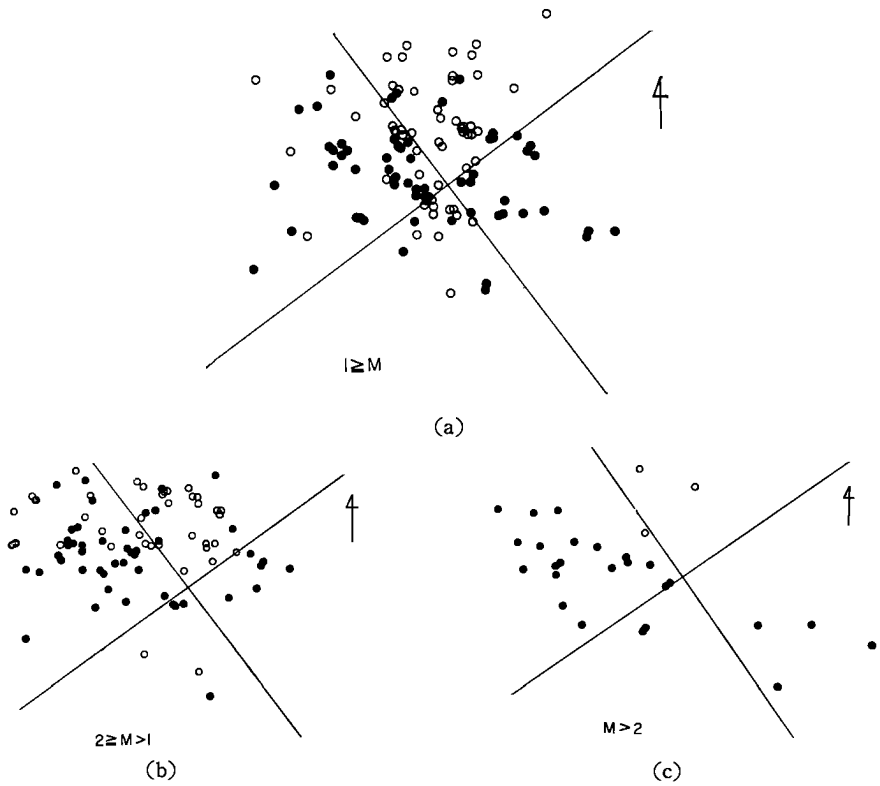


Fig. 12. Distribution of first P motion for each magnitude.

respectively.

The distribution is divided into 6 regions previously mentioned as Fig. 11 (a)-(f). The irregularity of distributions in Fig. 10 seems to be owing mainly to two reigions, that is region (2) and region (6). Figs. 12 (a)-(c) indicate the summed up distribution for each magnitude. From these results of micro-earthquakes, it can be said that the axis of maximum pressure lies approximately along the east-west direction in this district and this tectonic pressure affects equally the mechanism of earthquakes down to magnitudes less than zero.

Comparison with the data obtained by the J. M. A. net-work :

To examine how the results obtained by our microearthquake observation are connected with the results from large earthquakes, we dealt with larger earthquakes by the data obtained by the J. M. A., the magnitude of which was mostly more than 4. Distributions of epicenters determined by J. M. A. are shown in Figs. 13, 14 and focal depth in Fig. 15. The earthquakes in Figs. 13. occured from 1926 to 1954 and Fig. 14 from 1955 to 1964. It is very difficult to compare the seismicity of larger earthquakes with that of micro-earthquakes in detail, for want of sufficient data of J. M. A. Nevertheless it may be said that, as a whole, large earthquakes and microearthquakes have

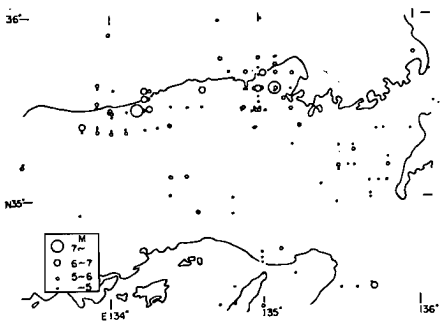


Fig. 13. Distribution of epicenters determindd by J. M. A. from 1926 to 1954.

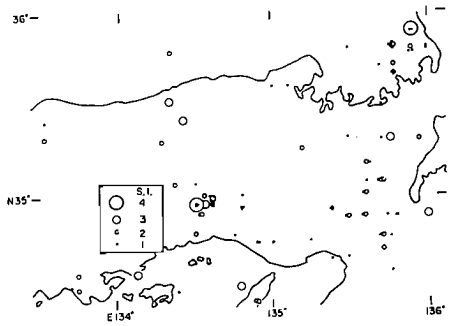


Fig. 14. Distribution of epicenters determined by J. M. A. from 1955 to 1964.

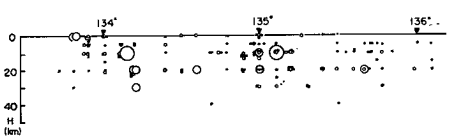


Fig. 15. Distribution of focal depth determined by J. M. A. from 1926 to 1964.

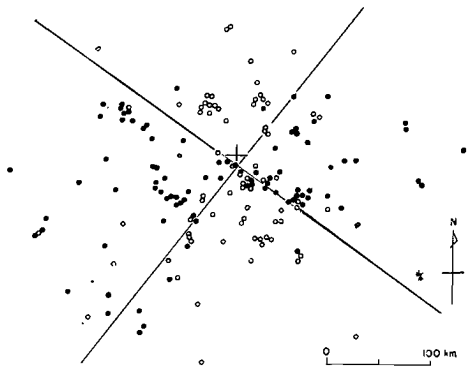


Fig. 16. Distribution of first P motions from the data of J. M. A.

a similar tendency in seismic activity.

As for earthquake mechanism a similar distribution of the first P motion previously mentioned is shown in Fig. 16. And we can find that earthquake mechanism is also nearly the same in both larger and microearthquakes. It is very interesting that an earthquake is caused by the same stress irrespective of its magnitude.

Some remarks:

From the geological point of view Maizuru structural belt separates two regions which have a different type of geological structure. Namely, the northern part of Maizuru structural belt is called Chugoku type and the southern part Tamba type, and these two types have different stages of the development of tectonic movement. Region 2 belongs to Chugoku type and is distinguished from other regions.[9] And after the study of earthquake mechanism it seems in Fig. 11 (b) that the direction of maximum compressional stress in region 2 rotates clockwise about 30° with regard to other regions.

As for Region 5 it is well known that the so-called Rokko movement have

continued upheaval still in holocene.[10] And the earthquake mechanism and the attenuation curves were not so uniform as in other regions.

Region 6 has already been reported by Okano and Hirano to be a high seismic region.

Recently the direction of the principal axis of stress was calculated using the geodetically surveyed data in this district. Our seismological results do not necessarily accord to that of geodecy. This fact suggests the stress which causes earthquakes might not be the recent stress acting on the crust, but the stress confined at one geological stage to the crust and only remaining as a latent earthquake.

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