Special Contributions, Geophysical Institute, Kyoto University, No. 4, 1964, 63-74

MICRO-EARTHQUAKES OCCURRING IN THE VICINITY OF KYOTO (1)

By

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(Received October 10, 1964)

Abstract

For the purpose of throwing the light on the nature of micro-earthquakes occurring in the vicinity of Kyoto, the routine observation was set about on Oct. 1963 at six observation stations founded newly in Kyoto, Osaka and Shiga Prefectures. The seismographs used are of vertical type with the maximum magnification of about 40,000 for vibration of 0.4 sec. According to the analysis of data obtained until Mar. 1964, the epicenters of micro-earthquakes are almost located in a belt-like region running from Wakasa Bay to Osaka Bay with the width of about 25 km. As for the focal depths, most of them belong to the crust. The fact that the micro-earthquakes occurred concently in the belt-like region might be due to the tectonic structure of the region as deduced from the behaviour of gravity anomaly there. In addition, the magnitude of the micro-earthquakes treated here are estimated to range from 1 to 3.

1. The six observation stations were founded after due consideration of the noise level that had been measured near the stations. The geographical locations of the stations are shown in Table 1 with their elevations. The positions of these stations are also plotted in Figs. 5, 6 and 7. The distance to the furthest station (Iwao) from Abuyama Station is about 55 km, and the distance to the nearest (Myoken) about

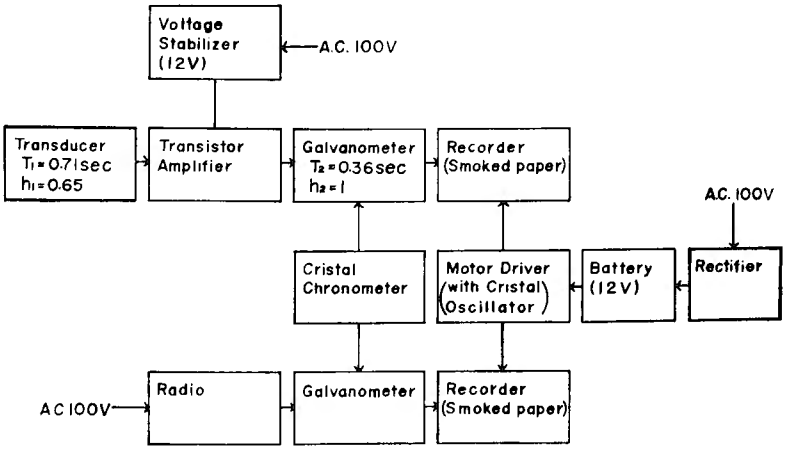


Fig. 1. Block diagram of the observation system.

Table 1. The geographical locations of the observation stations

Stations	Lat. (N)	Long. (E)	Level (km)
Abuyama	34°51′24.4″	135°34′22.4″	0.22
Myoken	34°55′38.0″	135°29′58.4″	0.60
Yagi	35°04′06.1″	135°30′33.2″	0.16
Kyohoku	35°10′38.0″	135°40′03.0″	0.26
Kamigamo	35°03′32.0″	135°45′56.3″	0.19
Iwao	34°52′57.0″	136°07′56.0″	0.40

15 km. All observation stations but Iwao are located within a circle of which radius is about 50 km.

The seismographs used at Abuyama, Kyohoku and Iwao are of vertical type with transistor amplifiers, and their maximum magnifications are about 40,000 for vibration of 0.4 sec. The seismographs used at Abuyama, Yagi and Kamigamo are of horizontal type as well as of the vertical type with the magnification of about 20,000 for vibration of 0.5 sec. Seismic motions are recorded in smoked papers at Abuyama, Myoken, Kyohoku and Iwao. Seismic motions at Abuyama, Yagi and Kamigamo are recorded in films. The constants of the transducers and the galvanometers used are listed in Table 2. For examples, the overall frequency response curves of seismographs used at Myoken and Yagi are shown in Figs. 2a and 2b respectively. Furthermore the observation system is shown in a block diagram (Fig. 1).

Table 2. Constants of the seismographs used

Stations	Vertical type*	Vertical and horizontal type**
Abuyama	$T_p=0.71$ sec, $T_g=0.36$ sec $h_p=0.65$, $h_g=1.00$	UD: $T_p=0.80$ sec, $T_g=1.26$ sec EW: $T_p=0.81$ sec, $T_g=1.14$ sec NS : $T_p=0.81$ sec, $T_g=1.14$ sec $h_p=h_g=1.00$
Yagi	Not equipped	UD: $T_p=0.80$ sec, $T_g=1.24$ sec EW: $T_p=0.81$ sec, $T_g=1.25$ sec NS : $T_p=0.81$ sec, $T_g=1.25$ sec $h_p=h_g=1.00$
Kamigamo	Not equipped	UD: $T_p=0.80$ sec, $T_g=1.00$ sec EW: $T_p=0.81$ sec, $T_g=1.07$ sec NS : $T_p=0.81$ sec, $T_g=1.07$ sec $h_p=h_g=1.00$
Myoken Kyohoku Iwao	$T_p=0.71$ sec, $T_g=0.36$ sec $h_p=0.65$, $h_g=1.00$	Not equipped

* with smoked-paper recorder, ** with film recorder

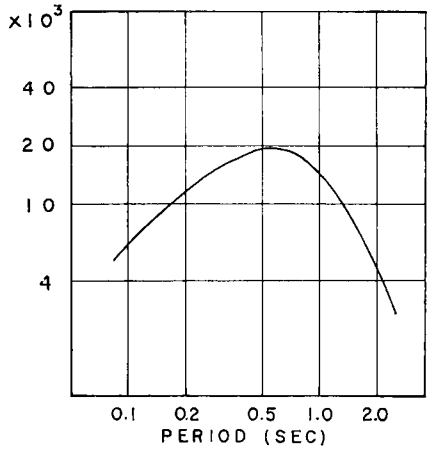


Fig. 2a. The overall frequency response curve of seismograph used at Myoken.

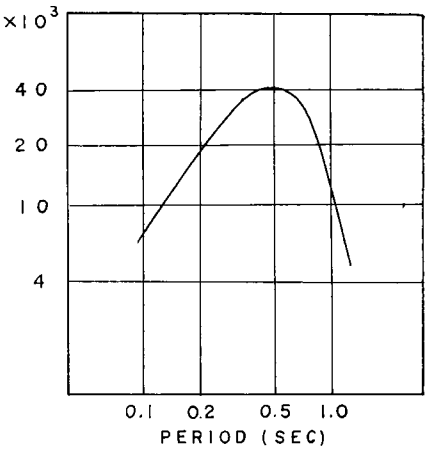


Fig. 2b. The overall frequency response curve of seismograph used at Yagi.

2. A large number of micro-earthquakes were recorded at every stations. As for the micro-earthquakes of which P-S times are less than 8 sec., the number of the events observed at Abuyama station is about 30 per month, which is thrice as many as the number of events observed at Iwao station. The number of the earthquakes observed at the other stations is between 15 to 30 per month. In these figures, earthquakes of which P-S times could not be read clearly are not included.

The frequency of P-S times at each station is shown in Fig. 3. The maximum frequency of P-S times at Abuyama station is at 1 to 2 sec. On the other hand, the maximum frequency is at 5 to 5.5 sec. at Iwao station. Fig. 3 shows that micro-earthquakes were most frequently observed in the vicinity of Abuyama, and least frequently in the vicinity of Iwao. As discussed just below, this fact is made clearer by the determination of epicenters.

As for the micro-earthquakes occurring from Oct. 1963 to the first decade of Mar. 1964, 62 events of them were observed simultaneously at more than four stations. The present authors determined the hypocenters of these events by use of the arrival times of four stations. The propagation velocity of P wave in the region concerned is assumed to be constant. Let t_i and t be the arrival times at the i-th observation station and the origin time respectively. If we denote the Cartesian coordinate of the i-th station by (X_i, Y_i, Z), then the coordinate of hypocenters (X, Y, Z) are given by the following equations:

$$(X_i-X)^2+(Y_i-Y)^2+(Z_i-Z_i)^2 = V^2(t_i-t)^2\,, \qquad i=1, 2, 3 \text{ and } 4,$$

where V is the propagation velocity of P wave. If we know the value of V, the velocity of P wave, we can solve the above equations and obtain the locations of

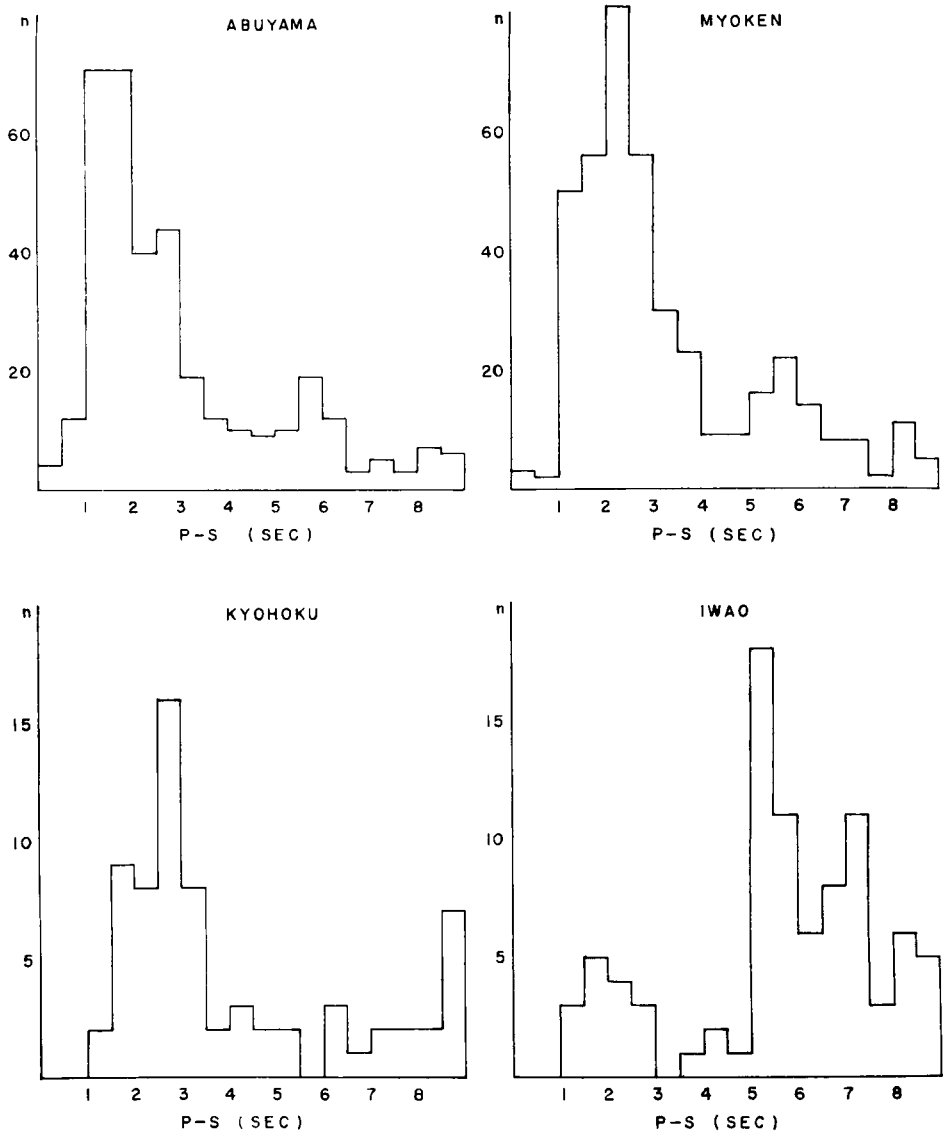
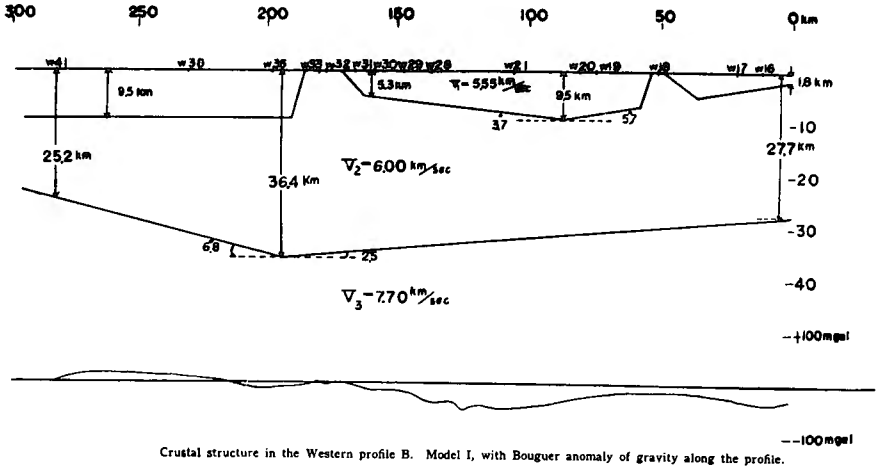


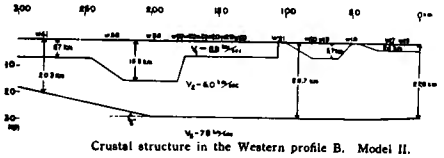
Fig. 3. Frequency diagram of the P-S duration times.

hypocenters (X, Y, Z) and the origin time t. The velocity of P wave in the region concerned has been determined by the Research Group for Explosion Seismology. According to the study of the Research Group, the layered structure and the velocity of P wave of Kinki District can possibly be explained with any of the two models. The crustal structures proposed by them are reproduced in Fig. 4. As known by any of the models, roughly speaking, the uppermost layer of the region has the velocity of 5.5 km/sec for P wave, and the lower one the velocity of 6.0 km/sec. The

present authors, taking into account these models, calculated the locations of hypocenters in cases of homogeneous layers with the velocity of 5.0, 5.5 and 6.0 km/sec respectively.



Crustal structure in the Western profile B. Model I, with Bouguer anomaly of gravity along the profile.



Crustal structure in the Western profile B. Model II.

Fig. 4. Crustal structures of the concerning region.

In case that earthquake could be observed at more than four stations, the least square method was applied to the normal equations of the above simultaneous equations. In connection, the geographical locations of the observation stations were transformed into the Cartesian coordinate referred to a temporary origin at the location of (135° 30′ 10.4″ E, 35° N). Numerical calculations were carried out by KDC-I.

The locations of the epicenters thus obtained are plotted in Figs. 5, 6 and 7. It is easily found from these figures that the distribution of epicenters is not profoundly influenced by the assumed value of velocity. In other words, the assumption that velocity is constant in the whole region concerned does not seem to affect significantly the distribution of epicenters. This fact was also ascertained by numerical experiments. On the contrary, the distribution of focal depths is largely dependent of the assumed value of velocity. This will be discussed later in detail.

The epicenters are distributed within a belt-like region running from Wakasa Bay to Osaka Bay. The belt-like region has the width of about 25 km. This region seems to correspond to the region where Bouguer anomaly of gravity changes remarkably (Tsuboi, C., [1961]). For comparison, the epicenters of earthquakes

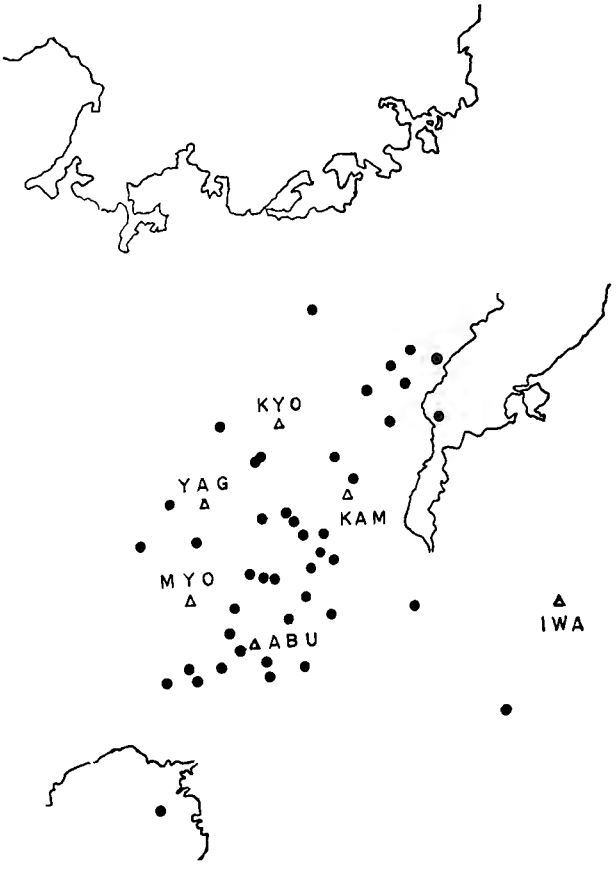


Fig. 5. Distribution of the epicenters of micro-earthquakes. (V=5.0 km/sec)

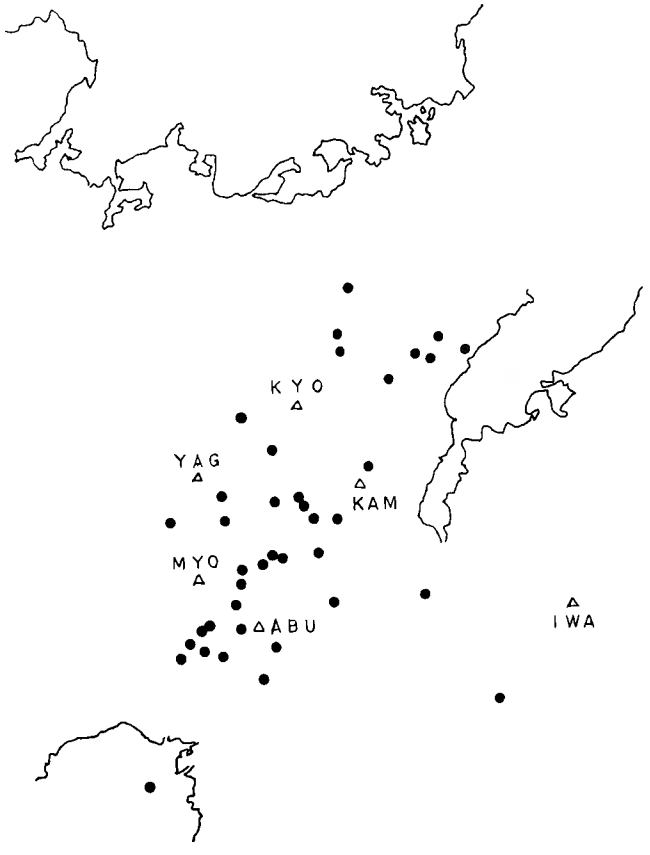


Fig. 6. Distribution of the epicenters of micro-earthquakes. ($V=5.5$ km/sec)

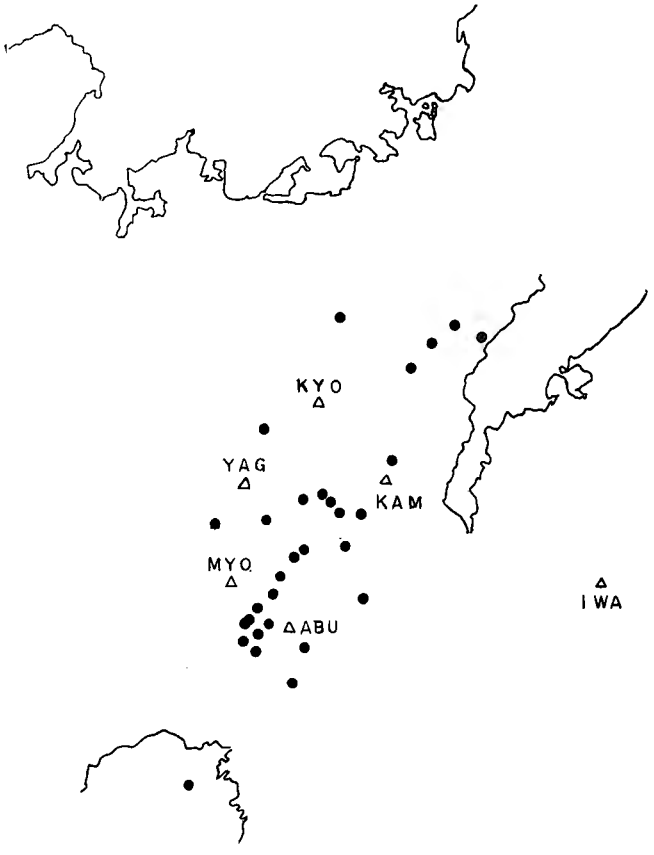


Fig. 7. Distribution of the epicenters of micro-earthquakes. (V=6.0 km/sec)

which occured from 1951 to 1960 in Kansai District are plotted in Fig. 8 with reference to the Seismological Bulletin of the Japan Meteorological Agency. These earthquakes are larger in magnitude than the earthquakes of which hypocenters were determined by the authors. It is, however, interesting that the larger earthquakes rather frequently occurred in the belt-like region mentioned above.

Fig. 8. Distribution of the earthquakes occurring from 1951 to 1960 in Kansai District (after Seismological Bulletin of J. M. O.).

The focal depths were also calculated by use of the above equations. But the focal depths obtained are not so reliable as the value of epicentral locations, since the value of Z is much sensitive to the value of V in the above equations. The higher the propagation velocity is assumed, the deeper the focal depths obtained become. In order to know the tendency of the distribution of focal depths, the hypocenters were projected to a vertical cross section. The cross section is perpendicular to the cross section passing through Abuyama and Myoken station. As shown by Fig. 9,

few deep earthquakes occurred beneath Iwao station, while deep earthquakes frequently occurred beneath Yagi station. When velocity is assumed to be too high, focal depth becomes indeterminable because of imaginary solution of Z. On account of it, the number of the earthquakes plotted in these figures decrease as the assumed velocity is increased.

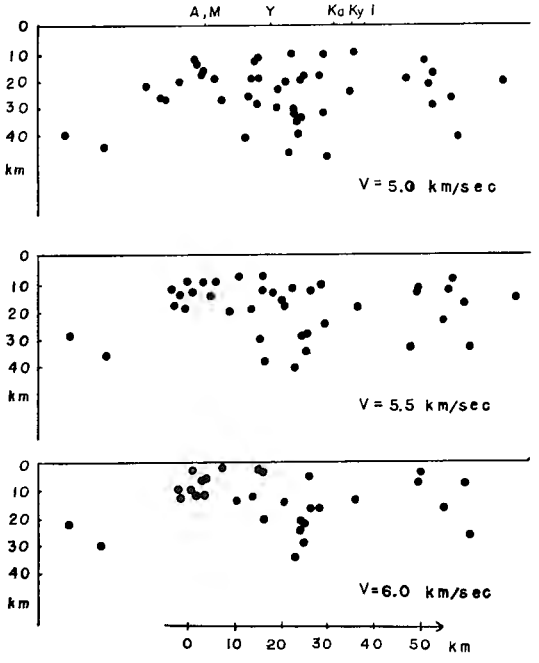


Fig. 9. Distribution of the focal depths of micro-earthquakes.

According to the study of the Research Group for Explosion Seismology, the region concerned has the velocity of 5.5 km/sec for the upper layer, and 6.0 km/sec for the lower layer. Therefore, the focal depth of earthquake which occurred in the lower layer would be deeper than the depth calculated by use of the assumed value of 5.5 km/sec, and shallower than that by use of the assumed velocity of 6.0 km/sec. On the other hand, the focal depth of earthquakes which occurred in the upper layer can be considered as the same as the value of focal depth calculated by use of the assumed velocity of 5.5 km/sec. The deepest of the calculated focal depths was a little over 40 km, which was calculated by use of the assumed velocity of 5.0 km/sec. Since the depth of 40 km belongs to the lower layer, the estimation that the deepest focal depth was about 40 km would be a little over estimated. Thus, the deepest focal depth might become shallower than 40 km and probably lie in the crust, if the layered structures would be taken into consideration.

3. Finally the present authors make reference to the magnitude of earthquakes treated here. It is well-known that magnitude is generally determined with the aid of Wood-Anderson seismograph. At Abuyama Seismological Observatory, Wiechert seismograph which is a displacement seismograph as Wood-Anderson seismograph is used for the routine observation. According to the records of Wiechert seismograph, the maximum amplitude of seismic motions observed at Abuyama has the period of 0.2 to 0.3 sec. for earthquakes of which P-S times are less than a few seconds. On the other hand, the period of the maximum amplitudes of near ditant micro-earthquakes recorded in our seismograph is also about 0.3 sec. It can be, therefore, considered that the maximum amplitude of seismic motion obtained by our seismographs has the same period as that obtained by Wood-Anderson seismograph. Wood-Anderson seismograph is of horizontal type, while our seismograph is of vertical type. We must take into account the difference of the type of seismograph for determining magnitude. According to the routine observation of three components of seismic motions at Abuyama Observatory, the maximum amplitude obtained by the seismograph of horizontal type is about two to five times as large as that obtained by the seismograph of vertical type.

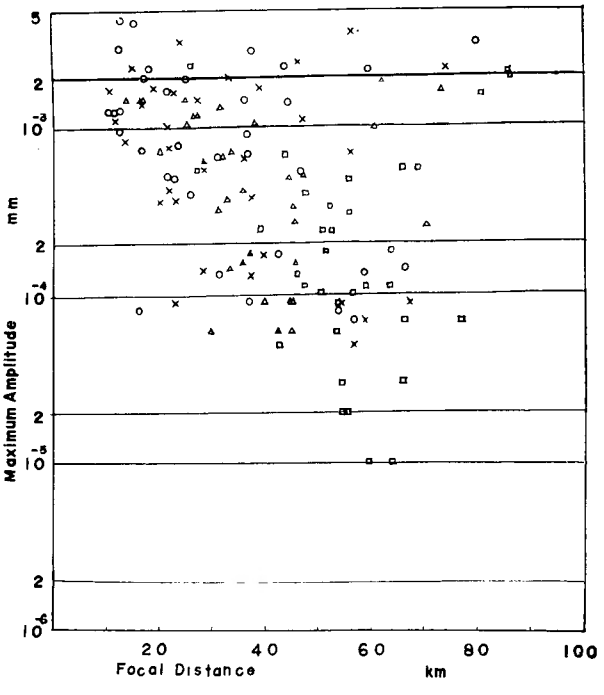


Fig. 10. Relationship between the maximum amplitudes and the hypocentral distances.

Fig. 10 shows the relation between the maximum amplitude and the hypocentral distance for the earthquakes treated here. The maximum amplitudes are taken in the ordinate, and the hypocentral distances in the abscissa. As known from Fig. 10, the maximum amplitudes at the distance of 100 km are estimated to be 10^1 to 10^3, the difference between Wood-Anderson seismograph and our seismograph being taken into consideration. In other words, the magnitudes of the micro-earthquakes treated here can be considered to be ranged from 1 to 3.

4. The near distant micro-earthquakes of which P-S times are less than a few seconds were frequently observed at Abuyama Seismological Observatory. As for these micro-earthquakes, the hypocenters and the distribution of them were determined with reliable accuracy with the aid of the simultaneous observations at many observation stations. As more observation stations have been planning to be established, hypocenters will be determined more accurately, and the distribution of hypocenters in the broader regions will be investigated in the near future. Furthermore, time sequence of occurrence of micro-earthquakes will be able to be made clear since the present observation is routinely worked.

References

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Tsuboi, C., 1961; Chikyû no Kôsei (Tsuboi, C. ed.), Chap. VII, Jishin, 163-192.