Aftershock Activity in the Vicinity of Kyoto

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Abstract

During the period from 1964 to 1968 about 50 earthquakes with a magnitude of 3.0 or greater occurred in the vicinity of Kyoto. These earthquakes are studied on their aftershock activity. Earthquakes of more than about 4.0 magnitude are accompanied by aftershocks almost without exception. Most of the earthquakes studied here did not have enough aftershocks that the customary statistical analyses of aftershocks—their time and spatial distributions, energy release and magnitude-frequency relation for aftershocks—are feasible. In this paper the aftershock activity of each earhtquake is examined in relation to the regional variation in two ways; one is the magnitude relation between the main shock and its largest aftershock; the other is the number of aftershocks. No significant feature can be obtained from the former examination, but the latter leads to an interesting observation about the regional variation of aftershock activity: that the earthquakes occurring in the southern part of the region concerned are followed by more aftershocks than those in the northern part.

1. Introduction

Aftershock activity is expected to provide us information on the physical characteristics of focal regions. From this point of view, the author studies aftershock activity in the vicinity of Kyoto. Earthquakes occurring near Kyoto are occasionally accompanied by aftershocks; however, the larger earthquakes do not necessarily have more aftershocks. This fact seems to suggest that aftershock activity in this region is dependent on the region where the earthquakes occur as well as on the magnitude of those earthquakes. Mogi[1] has studied regional variations of aftershock activity in and near Japan and has described their systematic features. This paper also examines systematic regional variations of aftershock occurrence.

2. Observational Data and Magnitude Determination

Since October, 1963 microearthquakes have been observed at six stations in the vicinity of Kyoto[2]. A vertical component instrument with maximum magnification of about 30,000 is installed at each station. Moreover, Abuyama Observatory, one of these stations, is equipped with three-component seismographs with different magnifications; these are 1.1, 15 and 170 respectively. Therefore magnitude determination is possible for all earthquakes observed. Magnitudes are evaluated by Umeda's formula[3] based on the observation of attenuation of seismic waves at the Matsushiro district.

During the period from 1964 to 1968 about 50 earthquakes with a magnitude of 3.0 or greater occurred in the vicinity of Kyoto. Earthquakes identified as aftershocks of other larger ones are not included in these 50, regardless of their magnitude. They are shown in the Table in order of magnitude, and their epicentral locations are shown in Figs. 1 and 4. Aftershocks following these earthquakes are examined. It is difficult to identify earthquakes as aftershocks especially in case of low aftershock activity. This author regards an earthquake as an aftershock according to a careful inspection of its P-S time observed by at least three stations.

3. Aftershock Activity

The Table shows that larger earthquakes are followed by more aftershocks than smaller ones in most cases. However, some exceptions are also shown in the Table. Even earthquakes with magnitudes as small as 3.0 are sometimes followed by many aftershocks[4], while only a few aftershocks are observed following some earthquakes with magnitudes of more than 4.0. For this reason, regional variations of aftershock activity are also studied.

Table Earthquakes with $M \geq 3.0$ which occurred in the vicinity of Kyoto from 1964 to 1968, arranged in order of magnitude. The magnitudes of their largest aftershocks and the numbers of aftershocks observed by at least three stations are also listed.

M_0	M_1	Number of Aftershocks	M_0	M_1	Number of Aftershocks	M_0	M_1	Number of Aftershocks
5.5	4.7	>100	3.7	2.3	6	3.2	2.0	18
5.0	4.4	> 50	3.6	2.2	16	3.2		0
4.7	2.7	>100	3.6	1.2	11	3.1	2.3	>50
4.7	2.4	>100	3.6	1.9	3	3.1	2.5	8
4.6	2.1	>100	3.6	1.7	3	3.1	2.4	2
4.6	3.4	8	3.6	1.7	2	3.1		0
4.5	2.1	50	3.5	1.5	4	3.0	2.0	12
4.5	2.4	1	3.5		0	3.0	2.3	5
4.4	2.2	19	3.4	1.0	13	3.0	1.4	4
4.3	2.5	16	3.4		0	3.0	1.6	2
4.1	2.4	3	3.4		0	3.0	2.0	2
4.0	2.7	10	3.3	1.1	4	3.0	1.8	1
4.0	2.8	2	3.3	2.2	3	3.0	1.3	1
3.9	0.5	1	3.3	1.0	2	3.0		0
3.8	2.1	28	3.3		0	3.0		0
3.8		0	3.2	1.9	>50	3.0		0
3.8		0	3.2	1.9	20			

Firstly, the difference in magnitude between the main shock (M_0) and its largest aftershock (M_1), M_0-M_1, is examined for each earthquake. Since the greater part of all the aftershock energy is released by the single largest aftershock, the value of M_0-M_1 is nearly equal to the logarithm of the ratio of the main shock energy to the total energy of all the aftershocks. Utsu[5),6)] and Mogi[1)] used M_0-M_1 as a measure of aftershock activity. Fig. 1 shows the spatial distribution of M_0-M_1 classified into two groups. No distinct regional variation of M_0-M_1 emerges from this figure. This is probably due to the small number of aftershcoks following most of the earthquakes studied here.

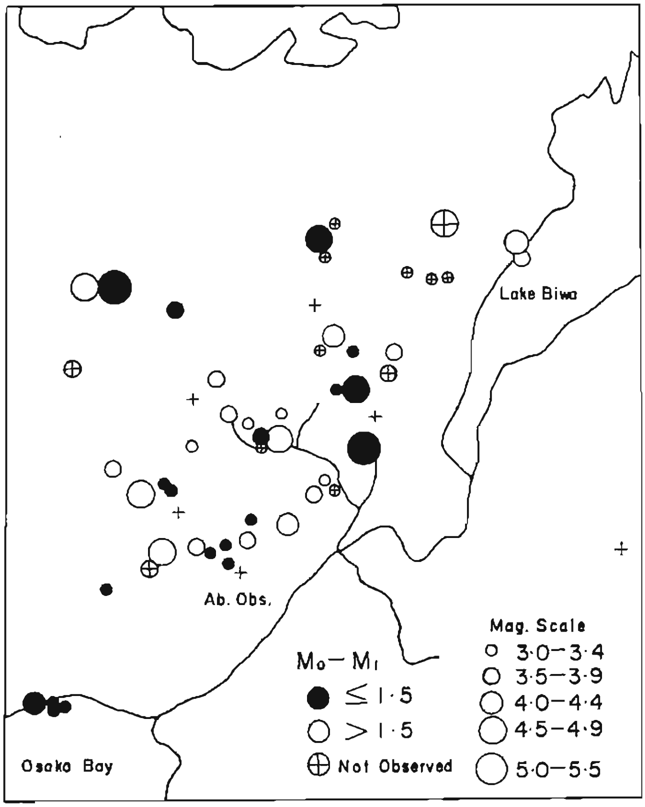

Fig. 1. Regional variations of aftershock activity indicated by M_0-M_1. The values are classified into two groups.

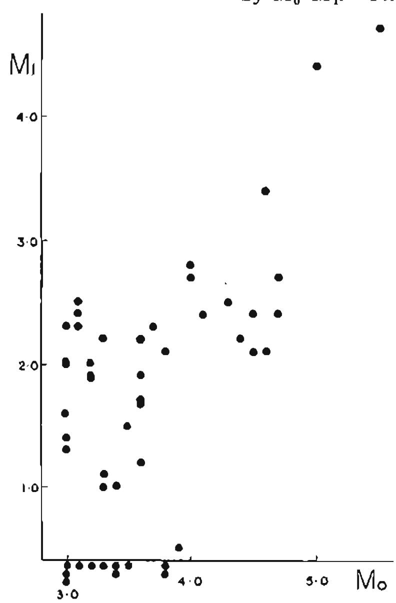

Fig. 2. Relationship between M_1 and M_0.

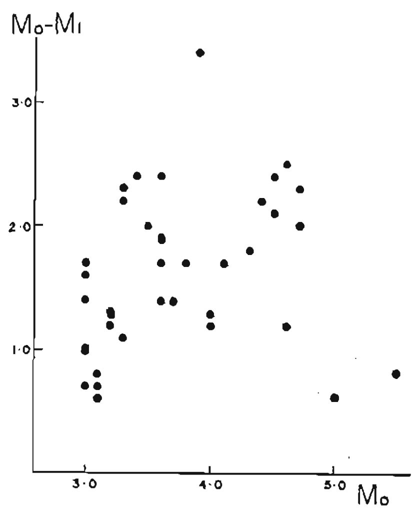

Fig. 3. Relationship between M_0-M_1 and M_0.

Fig. 2 shows the relationship between M_1 and M_0, and Fig. 3 the one between M_0-M_1 and M_0. In Fig. 2, M_0 is only plotted below the axis of the abscissa for earthquakes followed by no aftershock. Fig. 2 shows that M_1 increases with M_0. As shown in Fig. 3, earthquakes with a magnitude of greater than 4.0 are followed by aftershocks without exception. Furthermore the difference in magnitude between the main shock and its largest aftershock is found to be less than about 2.5. It is also noted that neither M_0-M_1 is linear to M_0 (Utsu) nor is M_0-M_1 constant regardless of M_0 (Båth[7]). The peak of M_0-M_1 is apparently seen in Fig. 3, but this may be due to insufficient data.

Secondly, the spatial distribution of the number of aftershocks observed by at least three stations is examined. The results are shown in Fig. 4, where closed, semi-closed

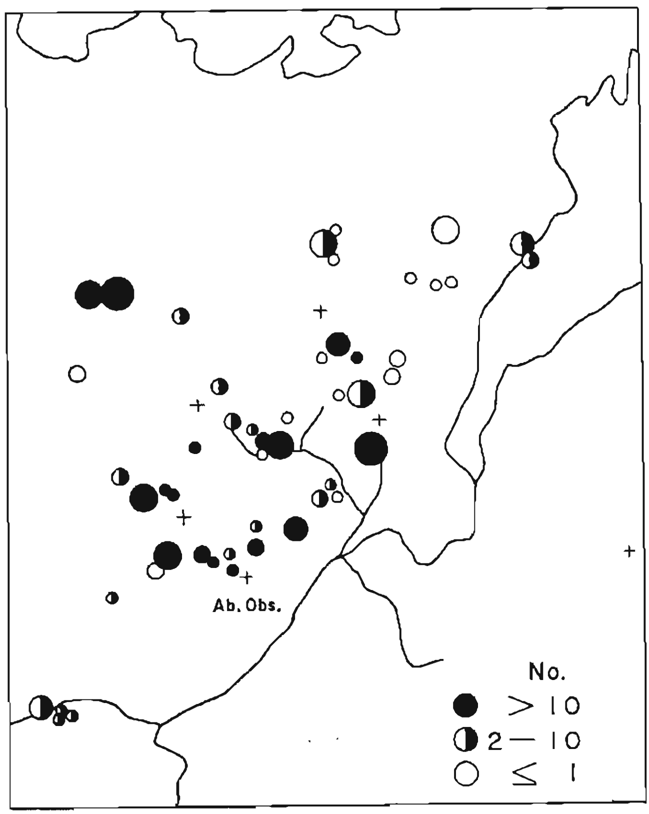

Fig. 4. Regional variations of aftershock activity indicated by the number of aftershocks observed.

and open circles denote that the number of aftershocks observed is more than 10, 2 to 10, and 1 or 0, respectively. The systematic regional variation is rather clear in this figure. Namely, earthquakes are followed by more aftershocks in the southern part than in the northern part of this seismic zone. Fig. 5 makes this tendency clearer. This figure shows the frequency distribution by the symbols of closed, semi-closed and open circles explained above. In this case the seismic zone is divided into three parts: northern, central, and southern. In the figure, (a), (b) and (c) show the frequency

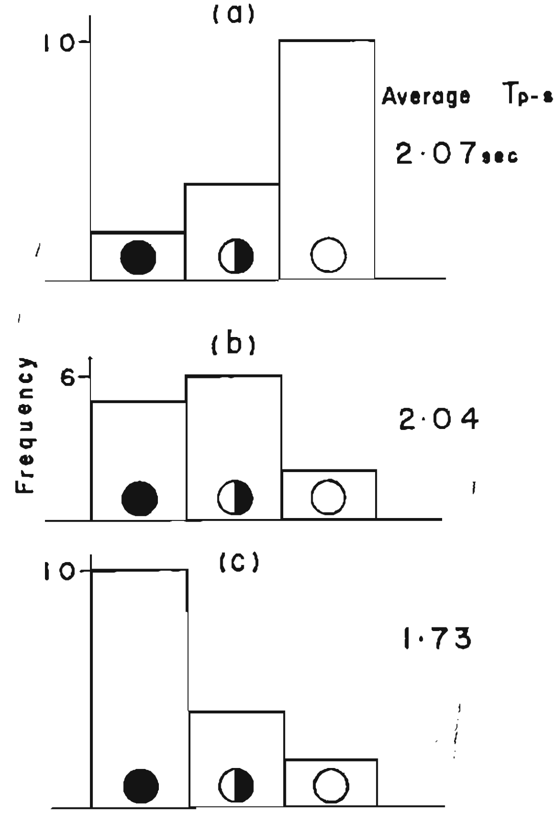

Fig. 5. Frequency distribution of symbols of closed, semi-closed and open circles. These symbols are represented in Fig. 4. (a), (b) and (c) show the distributions at the northern, central, and southern parts of the seismic zone, respectively.

distributions for these northern, central and southern parts, respectively.

4. Discussion and Conclusion

The prevailing method of studying aftershock activity is to examine the time and spatial distributions of the aftershocks, the energy release in the aftershock sequence, or the magnitude-frequency relation of the aftershocks. Unfortunately, because of the small magnitude of the main shocks under study, we have not been able to observe enough aftershocks for such statistical studies to be applied. Thus M_0–M_1 is used as a measure of aftershock activity in Utsu's and Mogi's studies, but this examination is not so effective in the present study.

The number of aftershocks observable naturally depends on earthquake magnitude, seismograph sensitivity and focal distance, so it may be premature to draw any conclusions from this examination unless these factors are taken into consideration. However, the magnitude distribution of earthquakes is nearly the same in all three parts of the region. Seismograph sensitivities are similar at all stations, except for the seismograph at Abuyama Obs. where sensitivity is reduced to half of that of the other stations because of the small ratio of signal to noise. The average values of P–S times of main shocks at the observation station having the smallest focal distance are 2.07, 2.04 and 1.73 seconds for the northern, central and southern parts, respectively, as shown in Fig. 5. The values are nearly equal for the northern and central parts, while that for the southern part is noticeably smaller. But this difference is not so significant as to alter the inference concerning regional variation.

The author is led to the conclusion that aftershock activity is higher in the southern than in the northern regions of the seismic zone in question. He plans subsequently to study this regional variation of aftershock activity with relation to regional variations of physical properties of the earth's crust and the occurrence of destructive earthquakes in the vicinity of Kyoto.

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