Change in Spatial Distribution of Earthquakes against Hypocentral Depth

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Change in Spatial Distribution of Earthquakes against Hypocentral Depth

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Abstract: A mathematical expression of spatial distribution of shallow shocks was studied in the previous paper. The same study is made in this paper for intermediate and deep earthquakes. Big earthquakes in the world and those in and near Japan are taken as data and the area concerned is divided into meshes with equal area. Then the frequency distribution of meshes $P(N)$ is expressed by a power type distribution,

$$P(N) = \gamma N^{-\delta},$$

where N is the number of earthquakes in a mesh. Since the distribution function is the same as that for shallow shocks, the numerical values of δ for shallow, intermediate and deep shocks are compared, after the reduction to a standard case is made. The values of δ decreases with increasing depth and this implies that the concentration of earthquakes is stronger as the hypocentral depth is larger. This tendency is identical both in world-wide distribution and in Japan. Exceptionally in the case of world-wide distribution of intermediate shocks an exponential distribution is adaptable as well as the power type distribution is. A discussion of this distribution is made.

1. Introduction

It has been concluded in our previous paper (Z. Suzuki and K. Suzuki, 1965) that the space distribution of shallow shocks is well represented by

$$P(N) = \gamma N^{-\delta}, \tag{1}$$

where N is the number of earthquakes in an unit area, $P(N)$ the number of areas in which N earthquakes occur, and γ and δ are numerical constants. The values of δ, as well as the type of distribution function, has been found to be independent of magnitude in the wide range of magnitude. A similar study will be made in this paper for intermediate and deep shocks, taking the world-wide data in "Seismicity of the Earth" (Gutenberg and Richter, 1954) and those in and near Japan in the Catalogue by Japan Meteorological Agency (1956). In this paper "intermediate" and "deep" shocks tentatively stand for the earthquakes having the focal depth of $300 \geq d > 60$ km and $d > 300$ km respectively.

2. Method

The method of analysis is similar to that in our previous paper. After plotting the hypocenters on a map, the whole area is divided into meshes with equal area and the number of earthquakes in each mesh is counted. Thus the frequency of meshes with a specified number of earthquakes is constructed. In order to calibrate the effect of dividing mode, the meshes are moved in various directions. If the frequency of mesh $P(N)$ has the form of "power type" distribution,

$$P(N) = \gamma N^{-\delta},$$

against the number of earthquakes in a mesh, N, the distribution should be represented by a straight line in $\log P(N)$–$\log N$ diagram. On the other hand, if $P(N)$ is the "exponential type" distribution,

$$P(N) = C\,10^{-\alpha N},$$

the result should be represented by a straight line in semi-logarithmic $\log P(N)$–N diagram. Thus the adaptability of distribution is examined. Sometimes a cumulative frequency,

$$\Sigma P(N) = \int_{\infty}^{N} \gamma N^{-\delta}\, dN \tag{2}$$

is convenient for the examination especially when the number of data is small. The result by this method can be easily transformed to that by another method. For instance, our expression is easily related with distribution of spatial distance between two neighbouring shocks, as has been minutely discussed in the previous study.

3. World-wide distribution

The numbers of intermediate and deep earthquakes with larger magnitudes than 6 listed in "Seismicity of the Earth" are 848 and 33 respectively. The whole world is divided into 414 meshes with an equal area which refers to $10°\times10°$ in latitude and longitude in equatorial zone. Frequency distribution $P(N)$ and cumulative frequencies for intermediate and deep shocks are seen in Fig. 1, in which the distribution for shallow shocks studied in the previous paper is also represented. This figure demonstrates that the distribution for deep shocks is fairly well expressed by the power type function,

$$P(N) = \gamma N^{-\delta},$$

as in the case of shallow shocks. Although a sudden decrease is sometimes seen at the right end of the plots, this can be reasonably explained by the small number of data. The numerical value of δ determined by the method of least squares is 1.21.

The plots for intermediate shocks show a slightly downward concave curvature in doubly logarithmic diagram, especially in cumulative distribution on right hand side of Fig. 1. Then the data are plotted in semi-logarithmic diagram. As seen in Fig. 2 the exponential type distribution function

$$P(N) = C\,10^{-\alpha N} \tag{3}$$

is more suitable as far as the present data are concerned. However it seems to be premature to conclude definitely that the world-wide distribution of intermediate shocks is different from other cases, considering that the number of data is small and also that the intermediate shocks in and near Japan show the same distribution (power type) as that for deep or shallow earthquakes, as will be stated in a later paragraph.

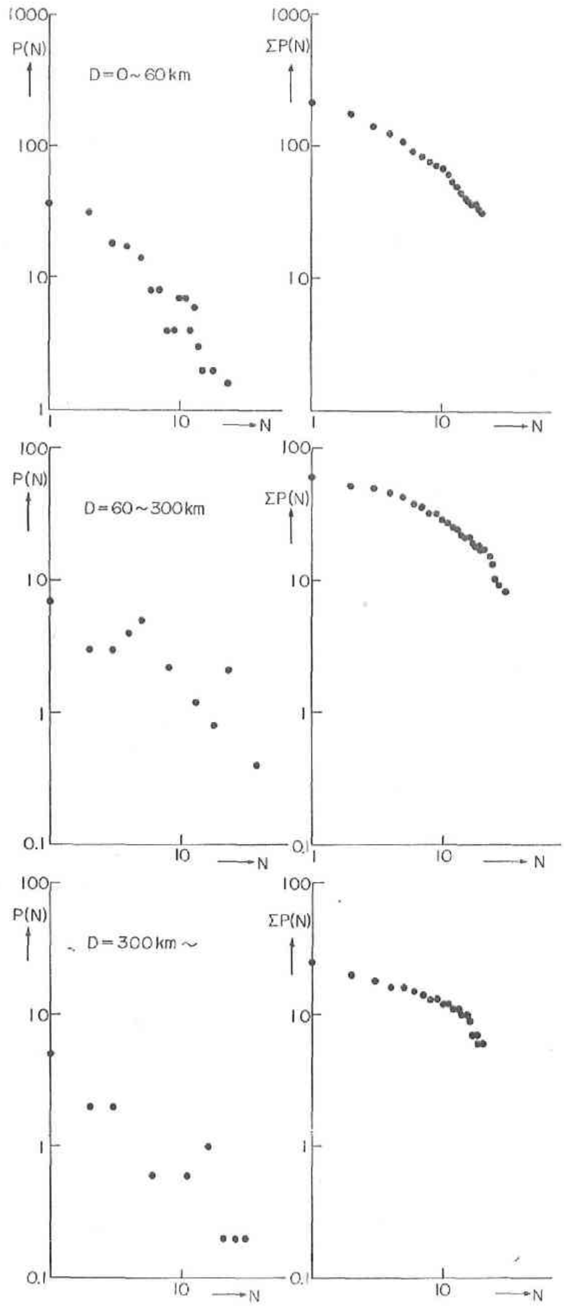

Fig. 1 $\log P(N)$ agaist $\log N$ in various ranges of hypocentral depth. (Big earthquakes in the world)

From these considerations, the problems should be left open to future question. If we provisionally adopt the power type distribution for intermediate shocks, the value of δ in this case is calculated to be 1.24. On the other hand, if we take the exponential type

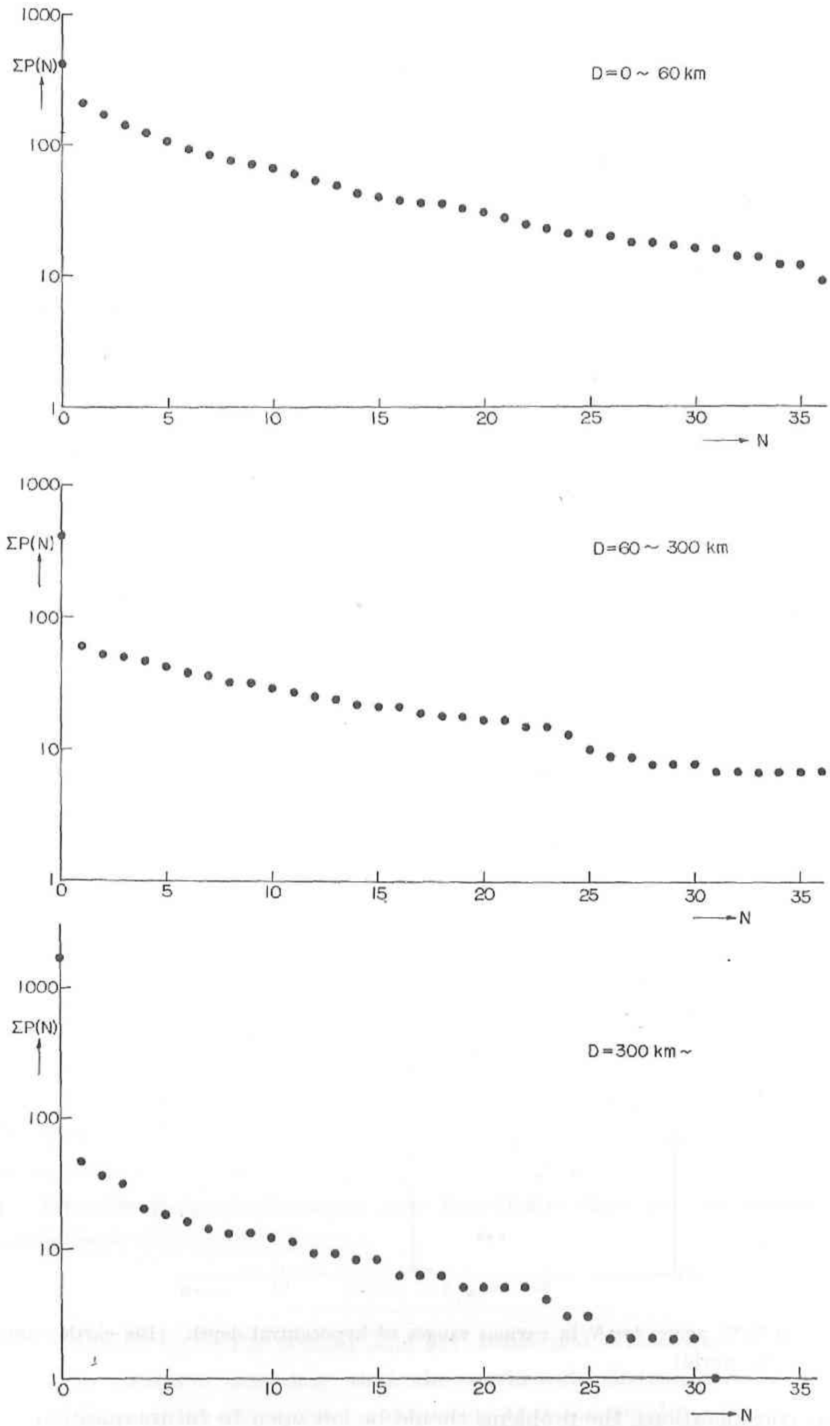

Fig. 2 $\log P(N)$ versus N for big earthquakes in the world.

distribution, the matter should be quite different. A detailed discussion in such a case will be made later.

4. The earthquakes in the vicinity of Japan

The catalogue by J.M.A. gives a complete data for the earthqueks ($M \geqq 5$) occured in and near Japan during 1926–1956. The numbers of intermediate and deep shocks in this catalogue are 668 and 169 respectively. The method of analysis is similar to the previous cases, the size of mesh being taken to be $1° \times 1°$. The frequency distributions $P(N)$ for shallow, intermediate and deep shocks are seen in $\log P(N) - \log N$ diagram, Fig. 3. The power type distribution holds good in every case, and numerical values of δ are 1.56, 1.74 and 1.12 for deep, intermediate and shallow shocks respectively. As seen in Fig. 4, the exponential type distribution is not adequate in this case even for intermediate shocks.

5. Comparison of numerical value of δ

As has been discussed in the previous paper, the frequency distribution $P(N)$ can be easily transformed to the distribution function of space interval S between two neighbouring earthquakes. When $P(N)$ is the power type function,

$$P(N) = \gamma N^{-\delta},$$

then the distribution of S must be expressed as

$$f(S)\, dS = (\gamma \cdot l^{\delta+1})\, S^{\delta-3}\, dS . \tag{4}$$

The probability of earthquake occurrence $\mu(S)$ against the distance S should be then written as

$$\mu(S)\, dS = (q-1)\, S^{-1}\, dS \qquad (q = 3 - \delta) . \tag{5}$$

This equation implies that the closer the interval, the larger the probability of occurrence. In other words, the earthquakes have the tendency of group occurrence of which the grade is indicated by the exponent δ or q. The comparison of numerical values of δ for shallow, intermediate and deep shocks, therefore, gives the difference in grade of group occurrence for these shocks, if any.

It should be noted here that the numerical value of δ determined by the method of least squares is influenced by the average number of earthquakes in a mesh or size of data, as was discussed by Aki (1961) and the present authors (1965). The relation between δ and the total number of meshes is given by

$$\log \sum_{N=1}^{\infty} P(N) = \delta \tan\theta - \log(\delta - 1) , \tag{6}$$

where θ can be determined from $\tan\theta = \sum (\log N)^2 / \sum \log N$. In this paper, a standard average number of shocks in a mesh is tentatively taken to be 2.35, and the value of δ obtained for the actual data is reduced to that in a standard case, where the value is denoted by δ'. The value of δ' are listed in Table 1 for the shallow, intermediate

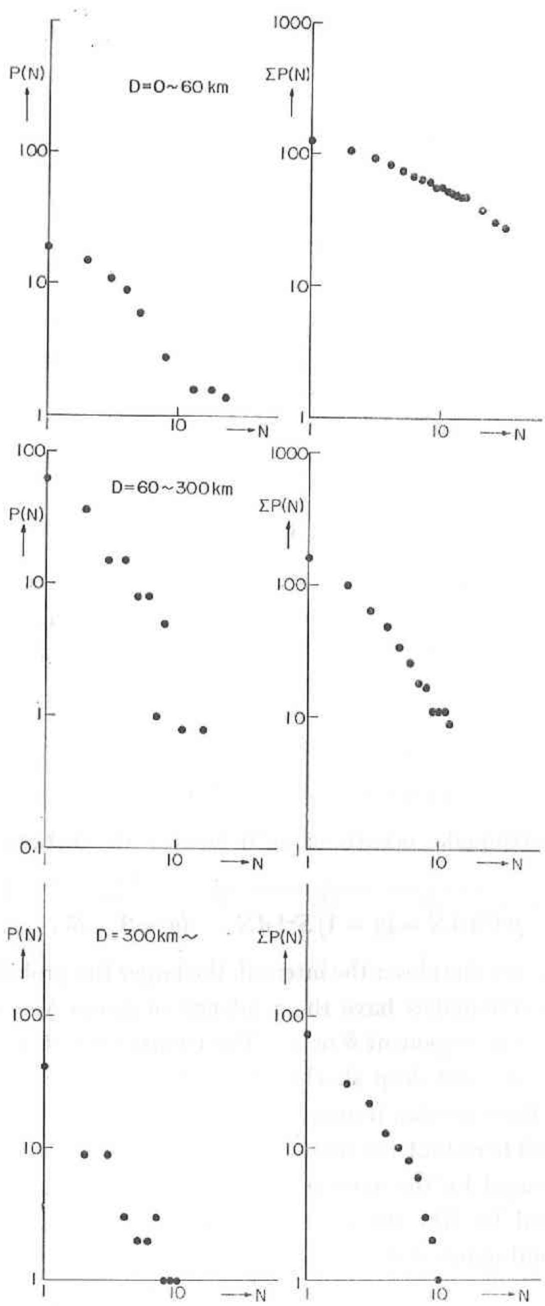

Fig. 3 $\log P(N)$ against $\log N$ in various ranges of hypocentral depth. (Earthquakes in and near Japan)

and deep shocks. It is evidently concluded that δ' decreases with increasing depth. This means that the tendency of group occurrence is larger for deep shocks than for shallow ones. The values of δ' is plotted in Fig. 5 against depth in abscissa. This figure

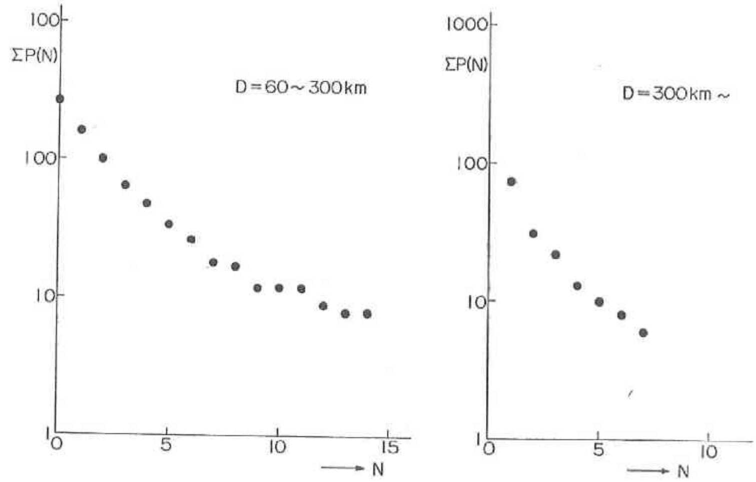

Fig. 4 $\log P(N)$ versus N for shocks in Japan.

Table 1 Values of δ′ by Eq. (6).

Depth (km)	Japan	World
0～60	2.40	2.56
60～300	2.10	2.14
300～700	1.57	1.05

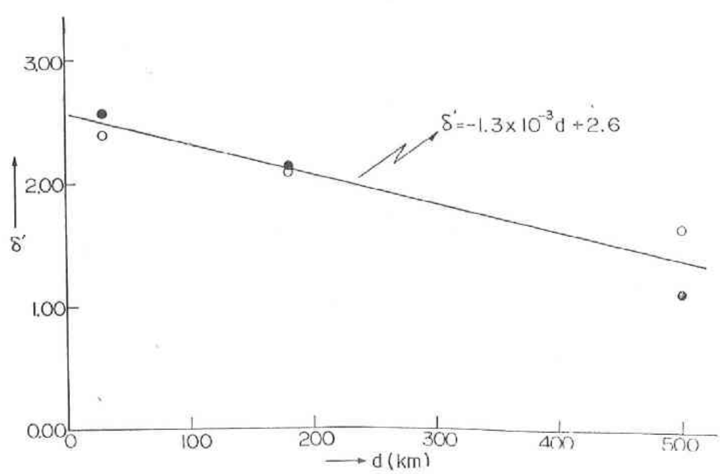

Fig. 5 Relation between δ′ and depth. (● World wide, ○ in Japan)

demonstrates that the variation of δ′ is identical for both big shocks in the world and those in and near Japan, that is, the change in the grade of group occurrence against depth is independent of locality of seismic area.

6. Discussion

In the case of intermediate shocks in world-wide data, we have shown that an alternative distribution function,

$$P(N) = C\,10^{-\alpha N},$$

can be taken as far as the present data are concerned. We will discuss here the situation when this type of distribution is adopted. As stated in the previous paper, there is another way expressing the spatial distribution of earthquakes, that is, the frequency distribution $f(S)$ concerning the distance S between two neighbouring shocks. The function $f(S)$ can be reduced from $P(N)$ in a similar way to that in the case of power type distribution. The mean distance $\bar{S}$ between two neighbouring shocks is written as

$$\bar{S} = \frac{l}{N}, \tag{7}$$

where l is the linear dimension of a mesh. Then

$$f(\bar{S})\,d\bar{S} = -\frac{1}{l}\,N\,P(N)\,dN. \tag{8}$$

As $P(N)$ is expressed by

$$P(N) = C\,10^{-\alpha N}$$

in the present case, the above distribution is written as

$$f(\bar{S})\,d\bar{S} = C\,l\,\bar{S}^{-3}\cdot 10^{-\alpha l \bar{S}^{-1}}\,d\bar{S}, \tag{9}$$

which corresponds to Eq. (4) in the case of power type distribution.

The probability $\mu(S)dS$ is defined as to be the unconditional probability with which an earthquake occur in a distance range between S and $S+dS$. On the other hand, $f(S)$ is the probability of earthquake occurrence under the condition that no earthquake occur within the distance smaller than S. Therefore,

$$\mu(S)\,dS = \frac{f(S)}{\int_S^\infty f(S)\,dS}\,dS. \tag{10}$$

Introducing Eq. (3) in this equation, we obtain

$$\mu(S)\,dS = \frac{S^{-3}\cdot 10^{-\alpha L S^{-1}}}{\dfrac{1}{\alpha^2 l^2} - \dfrac{1}{\alpha l^2}\left(\dfrac{1}{S} - \dfrac{1}{\alpha l^2}\right)\cdot 10^{-\alpha l S^{-1}}}\,dS$$

$$= \frac{\alpha^2 l^2}{S^3\,10^{S^{-1}} - S^3 - \alpha l S^2}\,dS. \tag{11}$$

If α and l are unity, this reduces to

$$\mu(S)\,dS = \frac{dS}{S^3\,10^{S^{-1}} - S^3 - S^2}, \tag{12}$$

which is shown in Fig. 6. Thus the unconditional probability of earthquake occurrence in this case is small for very close distance and has a maximum value at some distance, decreasing with increasing distance beyond that.

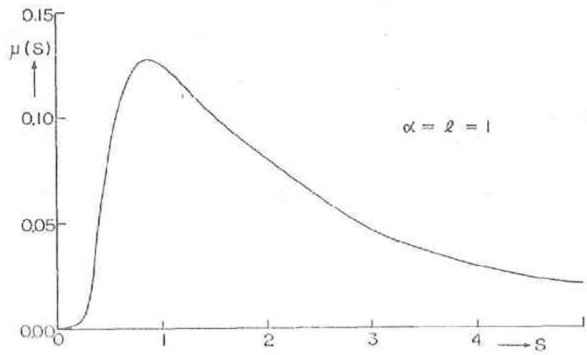

Fig. 6 $\mu(S)$ against S in the case of the exponential type distribution.

7. Conclusion

The conclusions of the present study are summarized as follows.

1) The spatial distribution functions of intermediate and deep shocks are expressed by the power type function,

$$P(N) = \gamma N^{-\delta},$$

as well as in the case of shallow shocks.

2) The numerical value of δ', which is the value of exponent δ reduced to a standard case, decreases with increasing hypocentral depth. This implies the stronger tendency of group occurrence for deep shocks than that for shallow ones. This variation is the same for both world-wide data and earthquakes in and near Japan.

3) For the intermediate shocks in world-wide data, an exponential type distribution,

$$P(N) = C\, 10^{-\alpha N},$$

can be also allowable. If this function is adopted, the probability of earthquake occurrence is represented by

$$\mu(S)\, dS = \frac{\alpha^2 l^2}{S^3 \cdot 10^{S-1} - S^3 - \alpha l S^2}\, dS,$$

while that for power type distribution is

$$\mu(S)\, dS = (q-1)\, S^{-1}\, dS.$$

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