Seismological Study on the Sakurajima Volcano (1)

— Classification of Explosions and Some Characteristics of These Explosions —

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Abstract

Volcanic explosions of the Sakurajima volcano are classified into six types according to the mode of occurrence of the volcanic micro-earthquakes before and after each explosion. In terms of this classification, some characteristics of the recent activity of the Sakurajima volcano are discussed.

The main results are as follows:

1) The rate of occurrence of D I type explosions has increased since 1965, whereas those of D III′ and D IV′ types have decreased.
2) Explosions of the same type occur in succession; and when one type shifts into another type, explosions of a form intermediate to both types are sometimes observed. From these facts it is considered that the conditions of the volcanic vent and the energy supply from the reservoir are reflected in the explosion types.
3) Large explosions are only observed in the D IV or the D IV′ types.
4) After the lava-pool has formed in the crater, D I type explosions occur frequently at the first stage, then D II type explosions begin to occur, and D IV type explosions occur last.
5) To judge from the arrival time difference of the air shock wave and the initial P wave of the explosion earthquakes, the origin of D I type explosions seems to be shallower than those of other types of explosion. This is confirmed by separate observation of the incident angle of the initial motion of the explosion earthquakes.

1. Introduction

The most recent activity of the Sakurajima volcano began in Oct. 1955, and more than 1700 volcanic explosions were counted up to the end of Dec. 1968. Although these explosions were grouped as Vulcanian type explosions, it is possible to classify them in further detail.

Generally, various surface phenomena, such as the quantity and the colour of the volcanic smoke, accompanying the explosions have been used to make the finer classifications. The weak point in these classifications is that these surface phenomena are not clearly observed when the explosions occur at night or in bad weather conditions.

Hence, the author tried to classify the recent explosions of the Sakurajima volcano according not to the surface phenomena but to the mode of occurrence of the volcanic micro-earthquakes before and after each explosion. By this method, the explosions always could be described adequately by routine seismic observation at the Sakurajima Volcanological Observatory of Kyoto University, and it was possible to classify all the explosions without exception.

In this paper, the results of this classification are shown; and on the basis of this classification, some characteristics of these explosions and the transitions of the explosion type which occur after the lava-pool has formed in the crater are discussed.

2. Observation Points and Data

Observation points and the location of the active Minamidake crater are shown in Fig. 1.

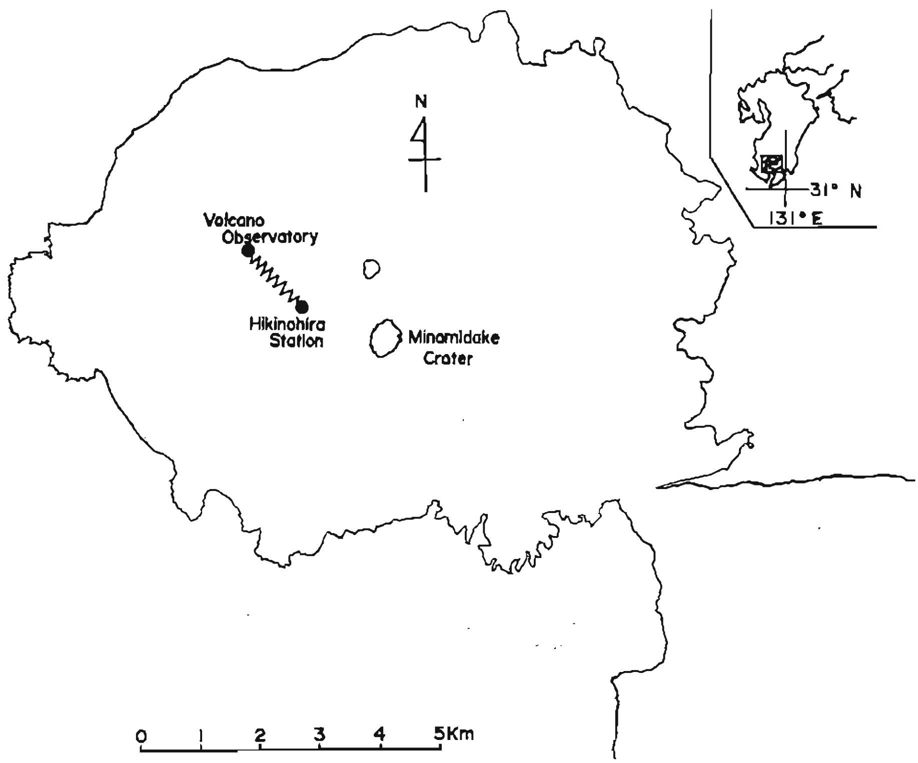


Fig. 1 Location of observation points and the active crater.

At the Hikinohira station, SH-II type electro-magnetic seismographs of three components are installed. Seismic signals from the Hikinohira station are recorded at the volcano observatory with a wire telemetering system. The data obtained by this system are used for the classification of the explosions.

At the volcano observatory, S-1000 type mechanical seismographs of three components are installed. The data of the incident angle of the first motion of the explosion earthquakes and the difference in arrival times from the air shook wave to the initial P wave of the explosions, are obtained by these S-1000 type seismographs.

The characteristics of the displacement magnification of the SH-II type and S-1000 type seismographs respectively are shown in Fig. 2.

On the maximum amplitude of the explosion earthquakes, the data of "Volcanic Report" by J. M. A. (Japan Meteorological Agency) are used.

The interval covered by this analysis is from Sept., 1963 to Dec., 1968.

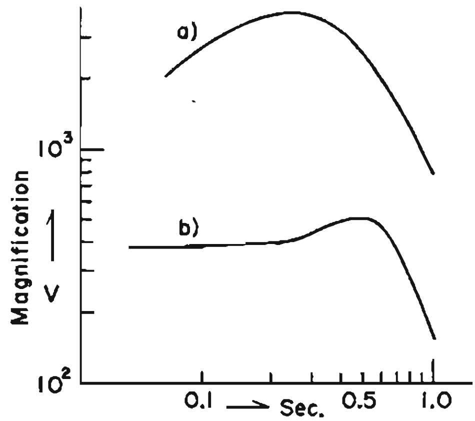


Fig. 2 Magnification characteristics of the seismographs.
a) SH-II type seismograph.
b) S-1000 type seismograph.

3. Classification

A classification of explosions according to the mode of occurrence of the earthquakes before and after each explosion was made in 1959 by Kagoshima Meteorological Observatory. But, unless the time interval which determines this mode defined exactly

Table 1 Definitions of Explosion Types.

Type	Definition
D I	For about two bours before and two hours after the explosion there occur scarcely any earthquakes.
D II	For about two hours before the explosion there occur scarcely any earthquakes, but immediately after the explosion earthquakes begin to occur.
D III	For about two hours before the explosion earthquakes occur, but after the explosion there occur scarcely any earthquakes.
D III′	The mode of occurrence of the earthquakes is nearly the same as for the D III type explosion, but the frequency of earthquakes before the explosion increases with time noticeably till the occurrence of the explosion.
D IV	For about two hours before and two hours after the explosion, there occure the earthquakes.
D IV′	The mode of occurrence of the earthquakes is nearly the same as for the D IV type explosion, but the frequency of earthquakes before the explosion increases with time noticeably till the occurrence of the explosion.

and within a definite short interval, the modes vary so widely and are so complex that the classification will fall into confusion. To avoid such confusion, the author defined this time interval determing the mode to be about two hours before and two hours after each explosion, and has classified the explosions into six types as shown Table 1 and Fig. 3.

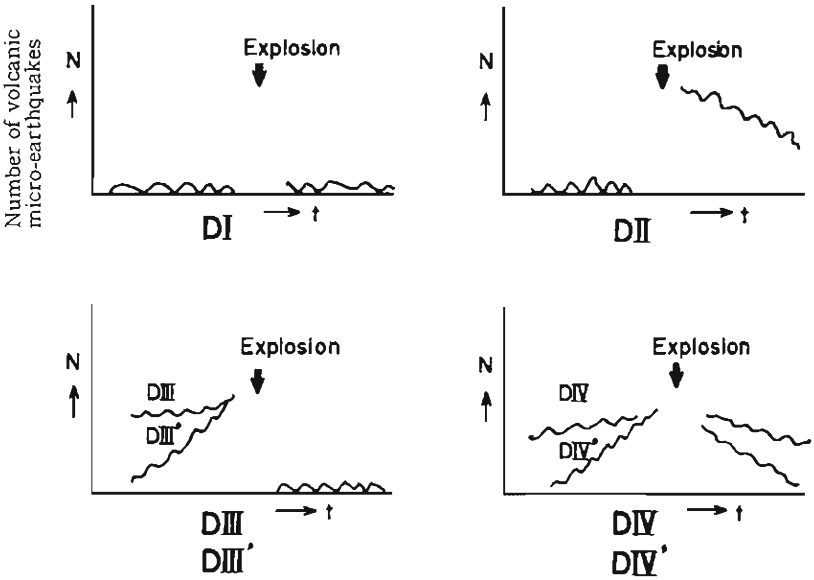
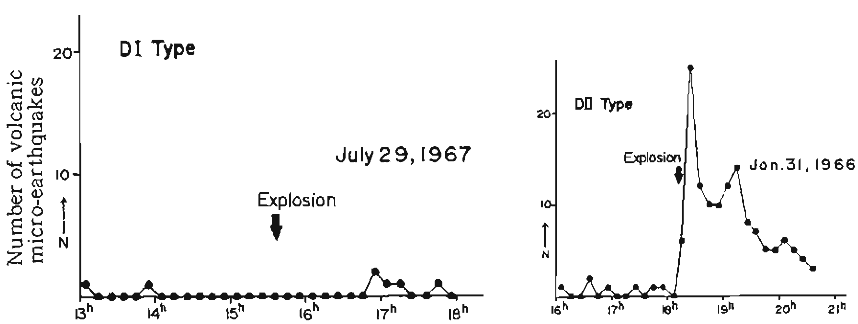


Fig. 3 Schematic representation of the occurrence mode of the earthquakes of each explosion type.

The other reason why this time interval is defined as about two hours is as follows; Some explosions are characterized by a remarkable increase in earthquakes beginning about two hours before the explosions, while other explosions have no such remarkable increase. Therefore, a classification based on a very clear contrast becomes possible, from about two hours before a given explosion.

It must be added that these categories of explosions are not, in reality, so neatly separates from each other; there sometimes exist intermediate types.



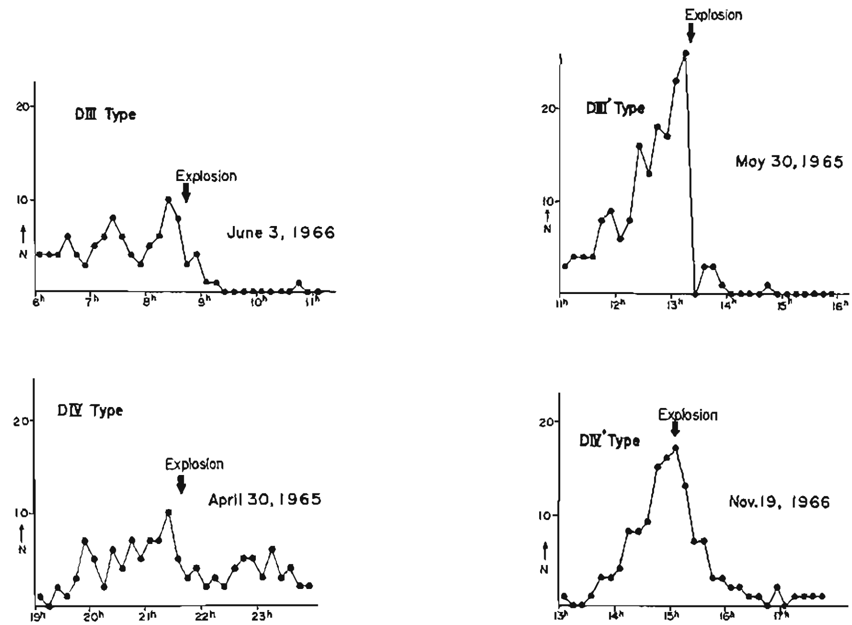


Fig. 4 Typical examples of the occurrence mode of the earthquakes of each explosion type.

In Fig. 4, typical examples of each explosion type are shown.

4. Some Considerations of the Classification Results

In order to find a clue to the mechanism producing such various explosion types and to find the relation between stages of volcanic activity and explosion types, some characteristics of each type of explosion are examined.

a) Annual variations of the occurrence ratios of each type of explosion.

Annual variations in the ratios of the occurrence of each type of explosion to the total number of explosion are shown in Fig. 5. In Fig. 5, the annual varation of the total number of explosions is also shown by a dotted line.

The ratio of the occurrence of D I type explosions has increased since 1965; on the contrary the ratio of the occurrence of the sum of the D III′ and the D IV′ type explosions has decreased.

No close correlation between the total number of explosions and the ratios of the occurrence of each type of explosion can be seen.

b) Probability of the successive occurrence of the same type of explosion.

Fig. 6 shows the percentage of the occurrence of each type of explosion following the D I, the D II, the D III and the D IV type explosions. Hatched areas represent the percentage of the successive occurrence of the same type of explosion. For instance, the percentage of successive occurrence of the D I type explosion is 65 per cent.

As to the D III type explosion, this type of explosion never occurs successively. But as shown in Fig. 5, the percentage of occurrence of this type is less than 10 per cent. Then it is safe generally to say that the possibility of the occurrence of the same type

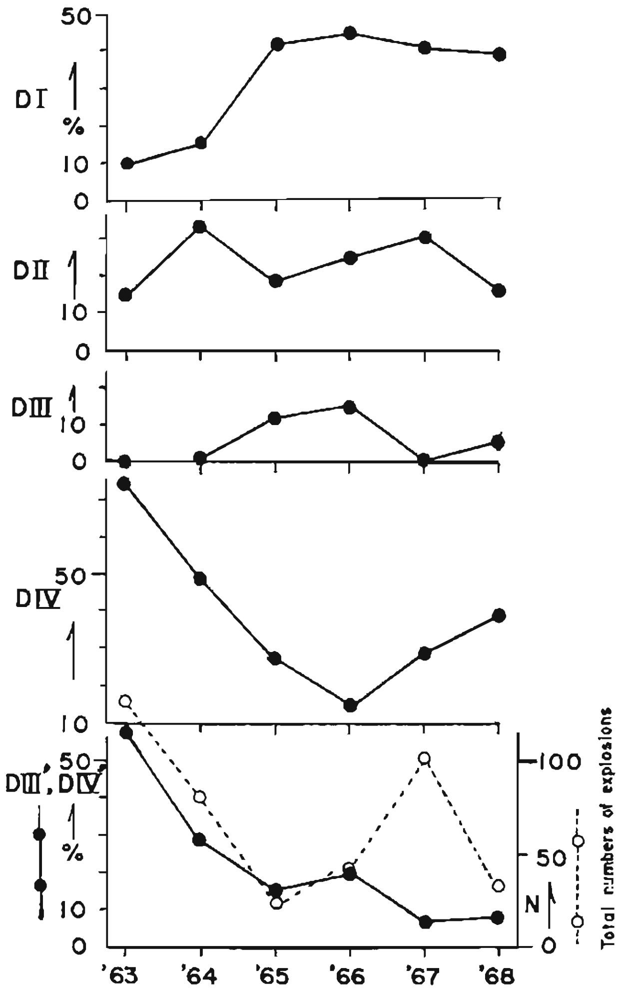


Fig. 5. Annual variations of the percentage of the occurrence of each explosion type, and the total numbers of explosions.

explosion in succession is larger than any other cases.

When one type of explosion changes into another one, a type of explosion intermediate to both types is observed at times. For instance, when a D I type explosion shifts to a D II type, the intermediate type between the D I type and the D II type explosion is observed.

$$\cdots \text{D I, D I, D I,} \longrightarrow \boxed{\begin{array}{c}\text{intermediate type}\\ \text{between D I and D II}\end{array}} \longrightarrow \text{D II, D II}\cdots$$

From above mentioned facts it is supposed that the conditions of the volcanic vent and the energy supply from the reservoir may be reflected in the type of explosion.

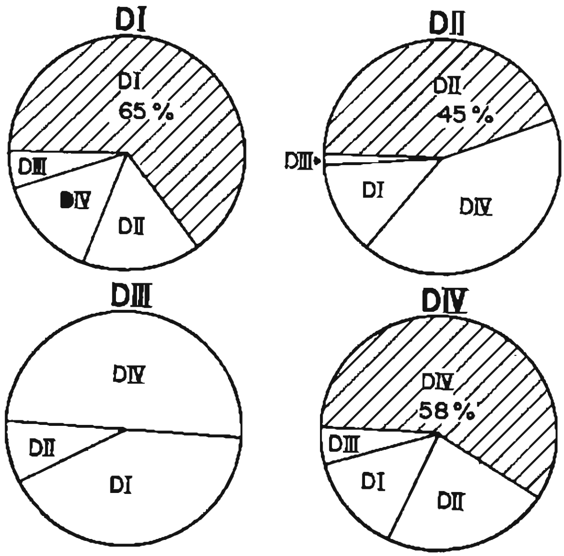


Fig. 6 Probability of the types of explosion which occur in succession.

c) Maximum amplitude distributions of each type of explosion earthquakes.

The large explosion earthquakes picked out of the data for the period Sep., 1963 to Dec., 1968, are listed in Table 2. All of the large explosions observed were limited to the D IV type or the D IV′ type. The percentage distributions of the occurrence of each type versus the maximum amplitudes of the explosion earthquakes are shown in Fig. 7. From this figure it appears that as the maximum amplitude of the explosion earthquakes becomes larger, the occurrence percentages of the D I, the D II and the D III type decrease, whereas those of the D IV and the D IV′ type increase.

Table 2 List of large explosions and their types.

	Maximum amplitude of explosion earthquake (μ)	Date	Type
1	163	′63 Oct. 23	D IV
2	153	′63 Dec. 12	D IV′
3	152	′63 Nov. 6	D IV
4	149	′64 Jan. 20	D IV
5	141	′63 Nov. 9	D IV′
6	136	′63 Sep. 23	D IV′
7	133	′67 Oct. 2	D IV
8	125	′63 Sep. 23	D IV′
9	124	′64 May. 20	D IV′
9	124	′67 Mar. 8	D IV′
10	121	′63 Oct. 12	D IV′

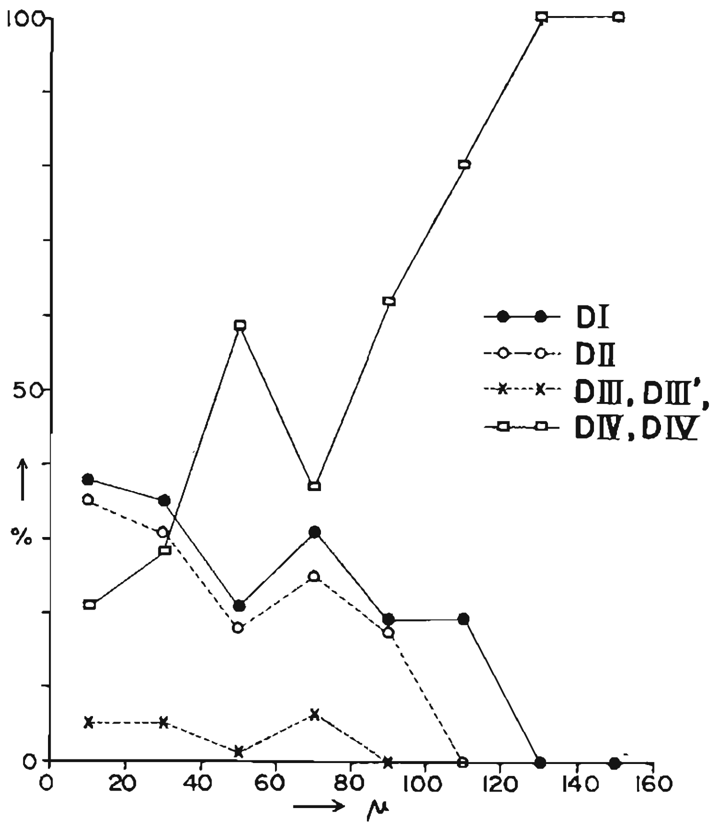


Fig. 7 Percentage distributions of the occurrence of each type versus the maximum amplitude of the explosion earthquakes.

d) Transition of the explosion type after the lava-pool formation.

An air view of the lava-pool formation in May 1967 is shown in Photo. 1. A lava-pool in the shape of concentric circles is seen in the crater. In 1967, lave-pool formations were observed four times.

The transitions of the explosion type in these stages of volcanic activity are shown in Fig. 8~11. Fig. 8 shows a change of type in May 1967; and the symbols × and ⊓ in the figure indicate respectively the time when the lava's ascent was surmised from seismic observation and the time when it was ascertained by air photograph. As shown in the figure, D I type explosions occurred frequently at first, then D II type explosions followed, and the D IV type began to occur last. In Fig. 9 and Fig. 10, the transitions of explosion type in July, October and November of 1967 are shown. The explosion type transition in November in Fig. 10 is given in Fig. 11 again with ten times magnification on the time scale. It is common among these four cases that after the lava-pools were formed in the crater, D I type explosions frequently occurred. Therefore, when the D I type explosion occur frequently as shown in Figs. 8~11 the lava-pool formation in the crater may be supposed.

From this it is considered that the focal depth of the D I type explosion earthquake

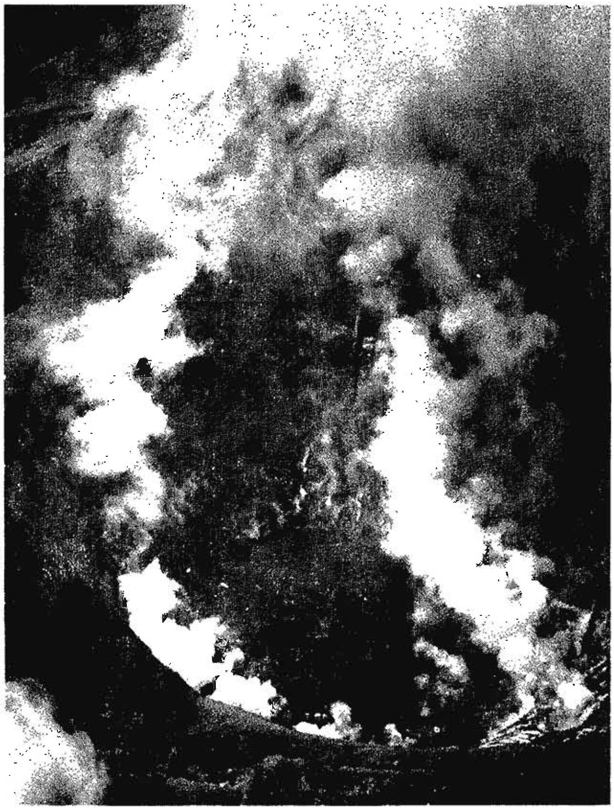


Photo. 1 Lava-pool formation in May 1967 (by the Yomiuri News Press).

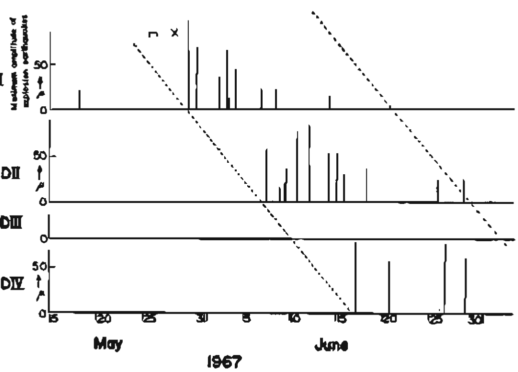


Fig. 8

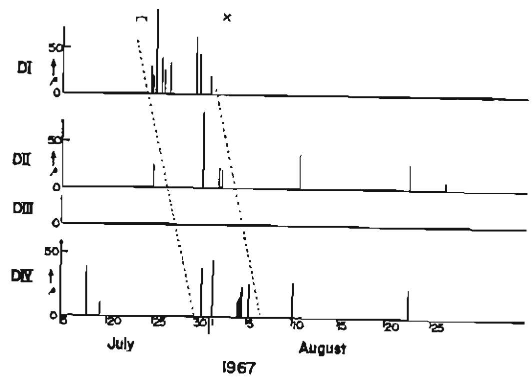


Fig. 9

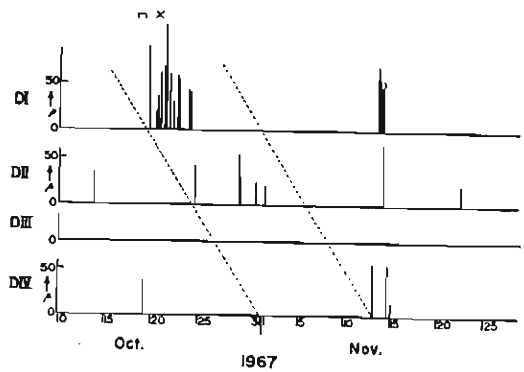


Fig. 10

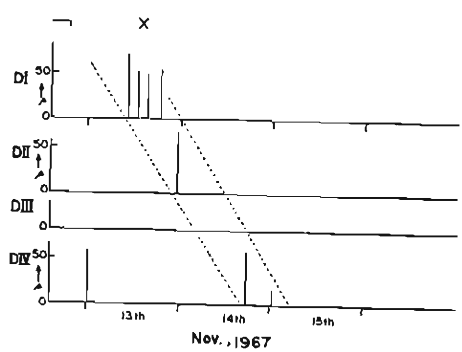


Fig. 8~11 The transition of the explosion types after the formation of the lava-pool in the crater. (on the symbols × and ⌐, see page 30.)

may be less than those of the other types. To check this, the differences in arrival time of the air shock wave, the initial P waves of the explosion earthquakes, and also the incident angles of the explosion earthquakes are examined. An example of the seismogram of an explosion earthquake recorded by the S-1000 type seismograph at the volcano observatory is shown in Photo. 2.

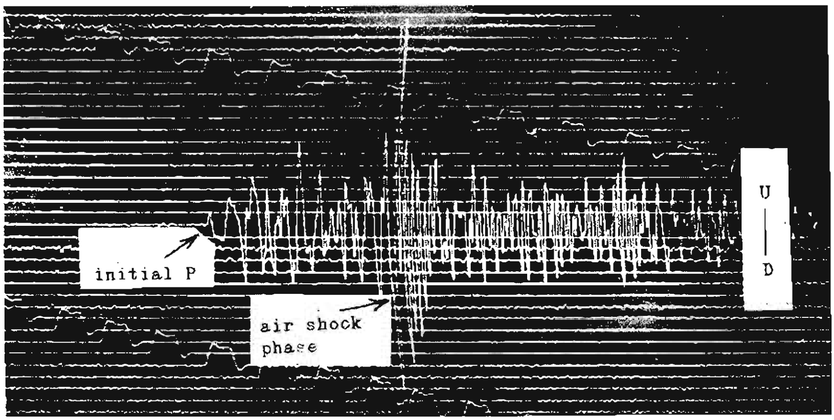


Photo. 2 An example of a seismogram of explosion earthquake.

Sometimes a clear phase of the air shock wave in the down sense is recognized, as shown in Photo. 2. Collecting those seismograms in which the air shock phase is clearly recognized as shown in Photo. 2, the arrival time differences between the air shock wave and the initial P wave are calculated. The results are shown in Fig. 12. From

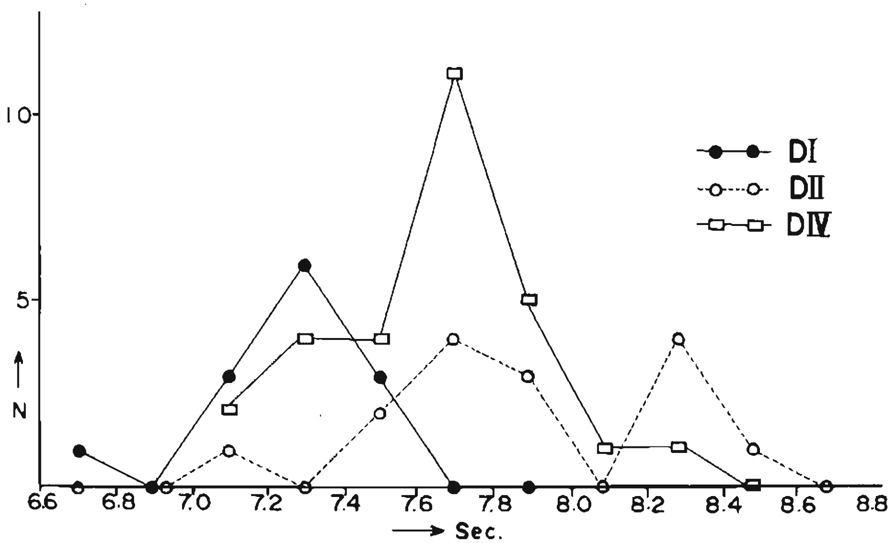


Fig. 12 Frequency distributions of the difference in arrival time from the air shock wave to initial P wave.

Fig. 13, it is found that the arrival time differences of the D I type are less than those of the other types. This means that in the case of the D I type explosion the travel time of the wave propagating from the explosion point in the volcanic vent to the surface of the crater is shorter than those in the other types. This is due probably not to the difference of the wave velocity propagating in the volcanic vent but to the difference of the distance from the explosion point to the surface of the crater.

Another evidence is given by the data of the incident angles of the explosion earthquakes. If the incident angle is measured as shown in the upper part in Fig. 13, the

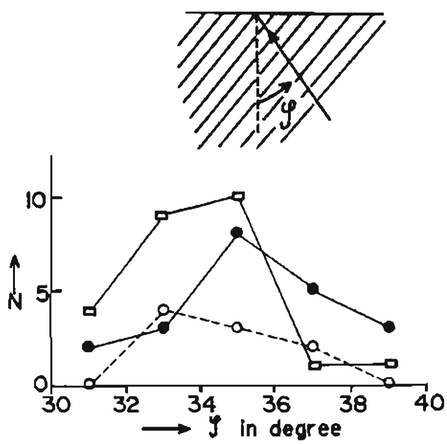


Fig. 13 Frequency distributions of the incident angles of the explosion earthquakes. (the symbols in the figure are the same as in Fig. 12.)

shallower the focal depth of the explosion earthquakes, the larger the incident angle becomes. Assuming Poisson's ratio to be 1/4, the incident angle of each explosion is calculated, and their frequency distributions are shown for each type in the lower part of the Fig. 13. As shown in Fig. 13, the incident angle of the D I type explosion earthquake is larger, on the average, than those of other types.

From these facts, it may be concluded that the focal depth of the D I type explosion earthquake is less than those of other type explosions.

5. Conclusion

The volcanic explosions of the Sakurajima volcano are classified into six types according to the mode of the occurrence of the volcanic micro-earthquakes during about two hours before and two hours after each explosion; and some characteristics of these explosions are obtained as follows.

1) The ratio of the occurrence of the D I type explosion has increased since 1965, whereas those of the D III′ and the D IV′ types have decreased.

2) The same type explosions occur in succession, and when one type shifts to another, the intermediate type of both is sometimes observed. These may suggest that each type represents the conditions of the volcanic vent and the energy supply from the reservoir at that time.

3) Large explosions are almost all of the D IV or the D IV′ type explosion.
4) After the lava-pool has formed in the crater, D I type explosions occur frequently at the first stage; then the following transition of the explosion type D I→D II→D IV was observed. Therefore, when these phenomena are observed as shown in Fig. 8~11 it may be supposed that the lava-pool has formed in the crater.
5) To judge from the difference between the arrival times of the air shock wave and of the initial P wave of the explosion earthquake, the origin of the D I type explosion seems to be shallower than those of the other type explosions. This is also suggested by observation of the incident angles of the explosion earthquakes.

Acknowledgments

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