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FOCAL MECHANISM OF VOLCANIC EARTHQUAKE OF THE VOLCANO ASO

By

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Abstract

During the recent active period, from April 1965 to March 1966, of the Volcano Aso, a swarm of volcanic earthquakes was observed at the Hondo observation room of Kyoto University. By analysing the data, the locations of foci of volcanic earthquakes are determined and the focal mechanism is discussed. The main results obtained are as follows: (1) the distribution of foci of volcanic earthquakes is varied with the volcanic activity, that is, the foci are located in comparatively narrow region before the eruption, but scattered after the eruption; (2) the characteristic earthquakes regarded as a rarefaction type are found, that is, the initial phases are all "pull" around the epicenter. These rarefaction type earthquakes are observed in the earlier time and the active time, but not in the later time.

1. Introduction

From summer of 1965 the Volcano Aso became active and the most violent eruption happened on October 31, 1965, of which the energy amounted to 10^{18} ergs, with a great deal of ash and fragments of rock and fresh lava. The tilt movement of the ground near the summit and the volcanic earthquakes were observed. The preliminary reports were already published (Wada, Kamo and Ono [1966]), and therefore in the present paper the focal mechanism and the distribution of volcanic earthquakes will be discussed.

The sign of initial phase of earthquake (push or pull) plays an important role in the study of the focal mechanism. In the volcanic earthquakes, however, such a study is infrequent because of unsatisfactory observation system and the inherent ambiguity of the initial phase. Then the study of mechanism of volcanic earthquake has not been progressed. Fortunately, in the case of the Volcano Aso, an interesting investigation during the prominently active period, that is, from 1932 to 1933, was reported by Sassa [1936]. He observed many volcanic earthquakes by setting three components of seismographs at the Aso Volcanological Laboratory of Kyoto University and obtained the following results: (1) at the stage before the eruptive stage (corresponding to a gradual upheaval of the ground near the crater found from observation by tilt-meter and implying the increasing of volcanic activity), the foci of earthquakes were located in comparatively narrow region, and the number of the earthquakes possessing the initial phase of push/the number of the earthquakes possessing the initial phase of pull (for brevity, this ratio will be represented by "push/pull") is about 1/2; (2) at the eruptive stage (corresponding to ceasing of the ground-upheaval and holding the maximum position, and explicitly active stage with eruption sequence), the foci of earthquakes were found in wider region than in the stage (1), and the ratio "push/pull" is about 1; (3) at the stage after the eruptive stage (corresponding to sinking of the ground near the crater and exhausting or gradual decaying of the activity), the foci of earthquakes were found in wider region than in (1) and (2), and the ratio "push/pull" is about 2.

On considering the above results, it must be noted that the results are based upon the observation at only one station and therefore the variation of the ratio "push/pull" does not always mean the variation of focal mechanism, but its possibility may be suggested.

In the present observation, utilizing five points observation, the epicentral positions obtained can be well determined in comparison with those in 1932–1933, and the sign of the initial phase (push or pull) is considerably well discerned. Hereafter the present observation may be considered as a chance for a study of the focal mechanism of volcanic earthquake.

2. Observation

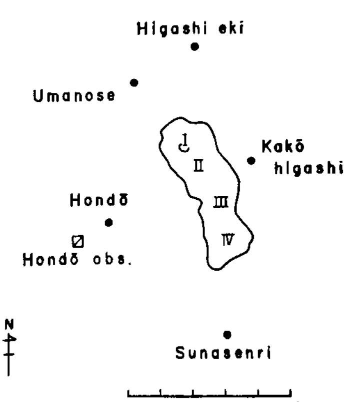

Fig. 1. The location of seismographs. The contour represents the rim of the crater.

The net of seismometers is illustrated in Fig. 1, that is, the pick-ups are arranged as surrounding the creater. These positions are named Hondo, Umanose, Higashieki, Kakōhigashi and Sunasenri, as seen in Fig. 1. Among these five positions, Hondo and Kakōhigashi are installed with three components seismometers, and the others are only with a vertical component. The main characters of seismometer used are listed in Table 1. The seismometers are installed on as rigid ground as possible to be kept off from any ground disturbance. The two stations, Kakōhigashi and Sunasenri, however, are not favoured with a rigid base and then installed on concreted base. The others are favoured with lava sheet.

Table 1. Description of seismographs

Station	Symbols	Type of Instrument	Galvanometer
Hondo	1		
Umanose	2	PK-110 vertical comp.	
Higashieki	3	(moving coil type)	0.3 cps
Kakōhigashi	4	T=1 h=1	
Sunasenri	5		

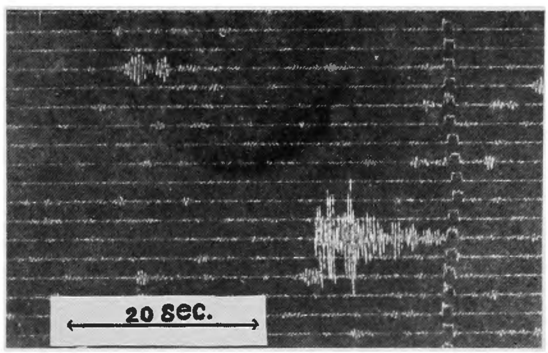

Fig. 2. The seismogram of the volcanic earthquake on January 4, 1966; recorded at Hondo.

The recording system is set at the Hondo observation room and usually smoked paper drums are driven. In such a favourable condition as a fine and calm night, magnetic tape recorders are driven to enable us to keep the time recordings accurate and the use of the endless tape recorder enables us also to record fully seismic signals without consumption of magnetic tape. An example of seismogram is shown in Fig. 2. As described in the following section, the records, of which the initial phases are identified for determining the position of focus and the sign (push or pull), are not beyond 10% of the total records owing to an essential ambiguity of initial phase of volcanic earthquake. The total number of earthquakes recorded amounts to about a thousand during about half a year. Therefore it is noted that the results as described below are not always sufficient for quantitative discussion from stastical viewpoint.

3. Seismicity and focal mechanism of volcanic earthquake

Assuming the velocity uniformity in the vicinity of the crater, the velocity of P-wave is estimated as follows: some velocities are estimated so that the error of position of each focus is as small as possible, and these velocities are averaged (in fact, the differences among these values are small). The final value obtained is 2.0 km/sec. On the other hand, the P-wave velocity of the uppermost part in the vicinity of the Aso caldera is obtained from several travel time curves of tectonic earthquakes and the value is compatible with the present value (Wada and Kamo [1964]). Thus this velocity may be reasonable to the present purpose in the first approximation. The determination of positions of foci is carried out for several examples as represented in Fig. 4. From these figures, generally speaking, these foci are gathered in a particular region north-eastwards the first crater (in present, the active crater), and these focal depths are also limited between 500 and 1,000 meters. This fact means that earthquakes are related immediately with the volcanic activity, that is, the uppermost magma reservoir, its physical properties and so on.

In order to study the correlation between volcanic activity and seismicity, firstly the variation of positions of foci must be compared with each volcanic active stage and then let the stages be classified as follows (according to Sassa's opinion as denoted in Section 1):

(1) The 1st stage represents the stage before eruption sequence. In this stage the ground near the summit of the crater uplifted gradually as derived from observation by tilt-meters and the bottom of the crater was dried up by heating accompanied with volcanic activity or sometimes was full of boiling water;

(2) The 2nd stage represents the stage of eruption sequence. In this stage the ground near the crater stopped the uplifting motion and held the maximum

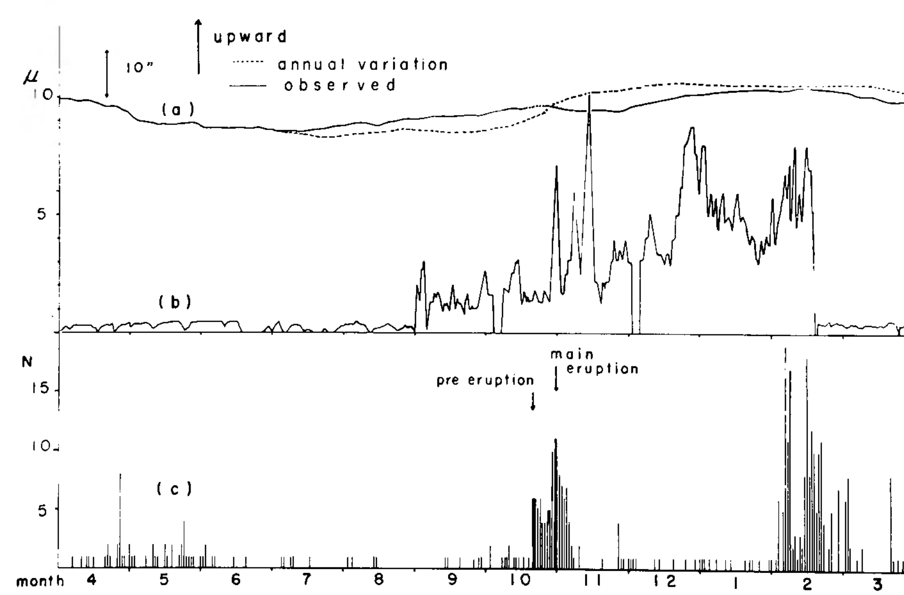

Fig. 3. (a) Variation of the ground tilt at Sunasenri.
(b) Mean amplitude of the 1st kind volcanic micro tremors at Sunasenri.
(c) Daily total number of volcanic earthquakes.

height. On opening the pit, the sequence of eruptions of Strombolian type occurred with a great deal of ash and fragments of rock or lava ;

(3) The 3rd stage represents the stage after eruption sequence. In this stage the ground near the crater began to sink gradually and the eruption ceased.

In order to show the character of each stage, the tilt motion at Sunasenri, the variation of amplitude of the 1st kind volcanic micro-tremor and the daily total number of volcanic earthquakes are illustrated in Fig. 3.

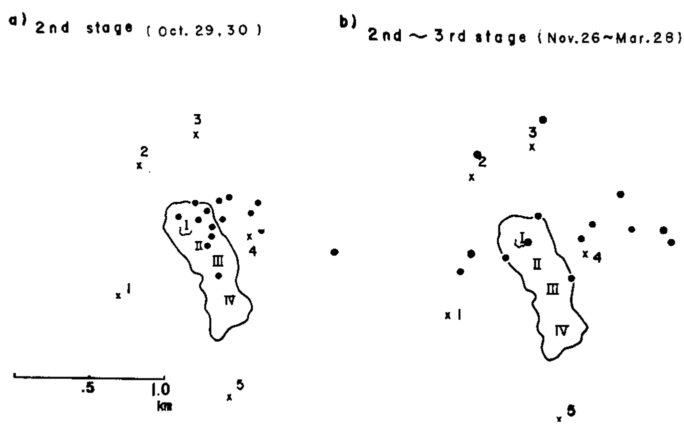

Fig. 4. Epicenter distribution of volcanic earthquakes.

During the 1st stage, the seismic observation net was not completed, and then the foci were not determined so accurately as in the later stages. The distributions of foci during the later stages are shown in Fig. 4(a) and (b). As seen in Fig. 4, in the earlier time of the 2nd stage the foci are concentrated in the east-northern part of the 1st crater and in the later time or the 3rd stage move gradually west-southwards and are scattered. Such a tendency is already pointed out by Sassa [1936], and the present result is compatible with it. This study of seismicity of the volcanic earthquake seems to be interesting for the problem of forecasting the volcanic eruption.

Another problem is related to the focal mechanism, and according to Sassa's result, the sign of the initial phase (push or pull) is closely related with the volcanic activity. And then the frequency of push or pull is examined on each station. The results are listed in Table 2 and 3. In the latter table the ratio "push/pull" is listed in order to compare the present result with Sassa's one. Excepting the value of Sunasenri, it may be concluded that in the 1st stage "push/pull" is about 1/2, in the 2nd stage about 1, and in the 3rd stage about 2. For the value of Sunasenri, it will be discussed later by considering a nodal

Table 2. Monthly total number of well observed volcanic earthquakes

Station	Sense	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
Hondo	push	2	5	3	2	1	3	15	3	3	0	35	21
	pull	8	10	4	1	0	1	13	5	2	3	26	7
Umanose	push							(12)	1	2	0	45	17
	pull							(5)	4	2	3	27	16
Higashieki	push							(11)	1	2	1	30	20
	pull							(6)	1	4	3	22	12
Kakōhigashi	push							(14)	0	1	0	24	7
	pull							(3)	3	3	3	19	21
Sunasenri	push	5	9	3	2	2	1	13	3	5	2	34	10
	pull	6	8	0	1	0	3	11	6	4	3	47	19

( ) indicates only the number during two days, October 29 and 30, 1965.

Table 3. Number of "push"/number of "pull"

Stage	Hondo	Umanose	Higashieki	Kakōhigashi	Sunasenri
1st	≈1 2				≈1
2nd	≈1	≈1	≈1	≈1	≈1
3rd	≈3	≈1	≈2	≈1/3	≈1/2

line, and in addition the base of the seismometer is somewhat wrong so that there may be some ambiguous reading of the initial phase. The result for the sign of the initial phase is also in good accordance with Sassa's one. Although it must be considered that the total number of earthquakes are not always sufficient for a quantitative discussion, the fact that the ratio "push/pull" varies from <1 to >1 at least could be unquestionable. (The focal depths also seem to be varied, that is, in the early stage those are deeper, and in the later stage shallower. The variation of depth, however, is not decisive because the accuracy of determination of focal depth is never sufficient to discuss the difference of depths.)

In the earlier time of the 2nd stage, that is, in the two days immediately before the main eruption of October 31, 1965, all foci are situated at the limited region, and the direction of the region from the opening pit is opposite to the direction in which the ejected materials are thrown. And it appears as if the region occupied by the foci were a store-room of the energy of eruption.

The existence of "pull" type of initial phase should be thought to be related with any focal mechanism, of which the existence has been usually considered to be questionable for volcanic earthquake. Then the earthquakes, of which both foci and signs of initial phases are obtained, should be examined

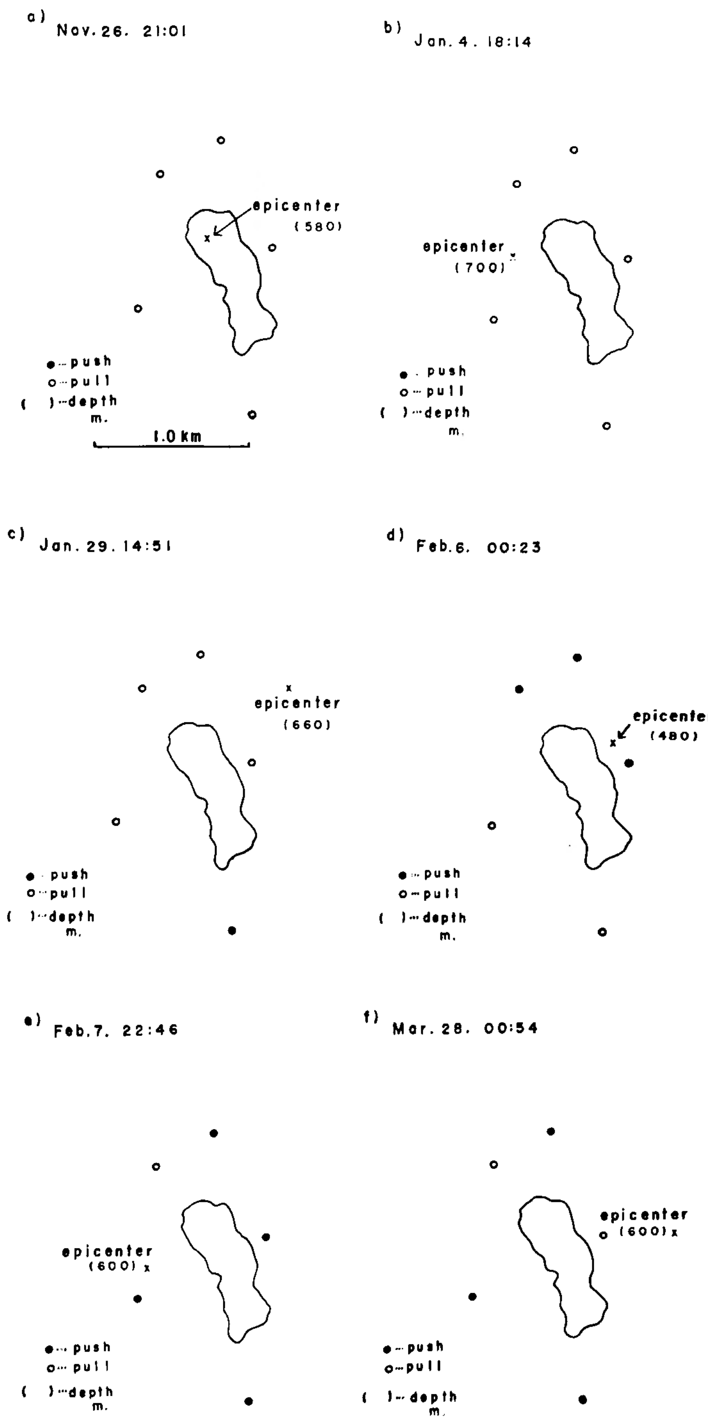

Fig. 5. Sense of the initial phase of volcanic earthquake.

in detail. Some examples of those are shown in six figures of Fig. 5. From these figures, for example, the events, Nov. 26, 21h 01m and Jan. 4, 18h 14m, have the foci within the observation net and all initial phases are "pull". Therefore the focal mechanism must be of a rarefaction type. The existence of rarefaction type in the focal mechanism is interesting while rather a explosive type (corresponding to all "push" initial phases) is suggested by the term of volcanic eruption. Furtheremore, the earthquakes representing the rarefaction type seem to occur frequently in the early stages, that is, the 1st stage and the earlier time of the 2nd stage, but scarecely in the later stage. This is important for a study of the focal mechanism in relation with the variation of volcanic activity. On the other hand, the occurrence of explosive type is scarecely and rather any tectonic type occurs most frequently. The present observation is not sufficient to determine the definite shape of such a tectonic type due to the shortage of number of observational stations and the smallness of net dimension in comparison with the depth of focus. It is, however, possible that some nodal lines are drawn. For example the initial phase at Sunasenri show frequently the opposite sign to the others and thus there may be a nodal line near Sunasenri in the south side of the crater. Also the three points net of the Japan Meteorological Agency is set westwards the crater, and from examining the records compared with those of the present net, the most remote station shows frequently the opposite sign to the others, and therefore there may be a nodal line.

From the above results, the variation of the ratio "push/pull" may be concluded to be related essentially with the focal mechanism of volcanic earthquake, and furthermore the existence of rarefaction type means the necessity of reconsideration on the mechanism of eruption. Although the definite shape of the focal mechanism is unknown, the region immediately above focus must be at least of "pull" type. In order to interpret this phenomenon, for example, the hypotheses that a release of internal pressure melts magma into beginning

Table 4. The summary of the seismicity and tilt motion associated with the volcanic activity

Stage	Time	Crater	Rate	Epicenter	Tilt Motion
1st	Apr. 6 ~ Sep. 30	crater bottom filled up with boiling water or dried up by heating.	$\approx 1/2$	concentrated ↓	upward
2nd	Oct. 1 ~ Feb. 28	a small pit opening on Oct. 21, a great eruption on Oct. 31, the sequence of eruptions of Strombolian type.	≈ 1	↓	equilibrium
3rd	Mar. 1 ~	crater bottom covered over with ashes.	≈ 2	scattered	downward

Rate is number of "push"/number of "pull"

Tilt Motion: upward means the ground near the crater uplifting.
downward means the ground near the crater sinking.

of eruptive stage, according to Rittmann [1962] or Uffen and Jessop [1960], may be accepted.

4. Conclusion

By observing the volcanic earthquakes accompanied with the recent volcanic activity of the Volcano Aso, the seismicity and the focal mechanism are re-examined in comparison with the results given by Sassa. In Table 4, the characteristic features in each stage are represented in order to summarize the present investigations. The main results are as follows :

(1) In the earlier time (or before the eruption sequence), the foci gather in a particular region, and in the later time those are scattered. The focal depths are betwee about 500 and 1,000 meters below the bottom of the crater.

(2) The existence of earthquake of rarefaction type is found. The earthquakes of this type are occurred frequently in the earlier time or before the eruption sequence, but scarecely in the later. And the variation of the ratio "push/pull" is acknowledged in the present case as well as in 1932-33, and the fact is thought to be derived essentially from the variation of the focal mechanism, and could be at least partly related with the existence of rarefaction type.

(3) The particular region occupied by foci occurring before the eruption sequence could be closely related with the direction in which the ejected materials are thrown at the main eruption, as if the region is the pressure origin.

These results are also interesting for the study of forecasting the eruption of volcano and therefore the more precise observation is necessary (partly in preparation). The study of rarefaction type will be especially minded in the relation with the mechanism of volcanic activity.

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