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Part 1. Observation of a New Type of Long-Period Micro-Tremors by Long-Period Seismograph

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Abstruct

The expectation that the volcanic activity may be indicated by studing the character of appearance of volcanic micro-tremors, has been entertained by many geophysists. The four kinds of volcanic micro-tremors found at the Volcano Aso, as classified by Sassa, are of comparatively short period. The existence of the volcanic micro-tremors of the 2nd kind, however, must be noted, and the period amounts to 3.5~7.0 sec.. Volcanic micro-tremors of such a long period are not always detected anywhere. Expecting an existence of volcanic micro-tremors of longer period than the 2nd kind, observation with a horizontal seismograph of long-period was carried out since Mar., 1958. A new type of long-period volcanic micro-tremors, amounty to 40~55 sec., was found, and the appearance of this volcanic micro-tremors is likely to be related with the volcanic activity.

1. Introduction

The Volcano Aso, one of the most active volcano in Japan, is situated at the north end of the Kirishima Volcanic Belt, and Naka-dake, the center of activity, is the middle one of the five central cones rising in the volcano. On the top of Nakadake there are four craters, the 1st, 2nd, 3rd and 4th in consecutive order from the north. It is pointed out that the center of activity had been shifted from the 4th to the 1st since Sep., 1932.

The geophysical study of the Volcano Aso was started with Sassa[1,2,3]. who carried out the observation of the volcanic micro-tremors and studied the nature of them. According to his classfication[4], the volcanic micro-tremors, accompanied with or preceded by the volcanic activities of the Volcano Aso, contain the four kinds of tremor, of which each has the particular type of wave and the variations of amplitude and period and also the frequency of occurence are closely related with the volcanic activities (see Table 1). A interesting fact is the existence of the volcanic micro-

Table 1. Volcanic micro-tremors at Volcano Aso (after Sassa).

Kind	Period in sec.	Velocity km/sec.	Type of tremors	Mechanism generated tremors
1st	ca. 1.0	1.0	surface wave (Love type)	internal eruption of volcanic gases
2nd	3.5~7.0	0.9	surface wave (Rayleigh type)	vibration of magma reservoir
3rd	0.5	—	(body wave)	internal eruption (only in active time)
4th	0.2	—	(body wave)	surface eruption

tremors of the 2nd kind characterized by the long period amounting to 3.5~7.0 sec.. Tremor of such a long period has not been usually observed, excepting that of Taal Volcano[5] Then the writer's attention[6] is attracted to the problem whether any tremor of longer period exists or not. Then a long-period seismograph is deviced and used for observation of volcanic micro-tremors at the Aso Volcanological Laboratory.

2. Long-period seismograph with horizontul pendulum

It is generally accepted that horizontal pendulum is more suited for design of long-period seismograph than vertical one. Then the writer tried to make a seismograph of horizontal component. The apparatus will be noted by LP-1, of which constants and main features are the following : the pendulum is sus-

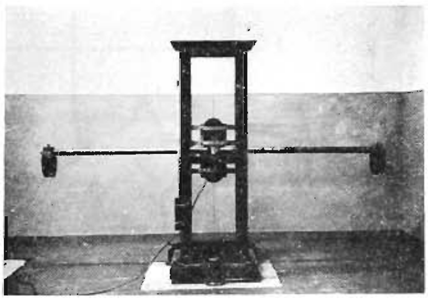


Fig. 1. Pendulum parts of horizontal component of long-period seismometer.

pended with piano-wire of 3 mm. in diameter, according to Zöllner's type and is attached with arms, of which the length amounts to 81 cm, and each end is attached with heavy mass of 4.5 kg. for increasing the moment

Table 2. Constants of long-period seismograph LP-1.

Mass of pendulum	$2\times4.5\times10^3$	grams.
Moment of inertia	6.7×10^7	c.g.s.
Equivalent length of pendulum	2×10^2	cm.
Length between center of gravity and rotational axis	25	cm.
Period of pendulum	180	sec.
Period of galvanometer	100	sec.
Internal resistance of galvanometer	685.7	ohms.
Critical damping resistance of galvanometer	1200	ohms.
Sensitivity of galvanometer	6.8×10^{-11} 1.3×10^{-7}	amps volts.
Magnification of maximum value	780	
Recording-drum speed	0.97	cm/min.

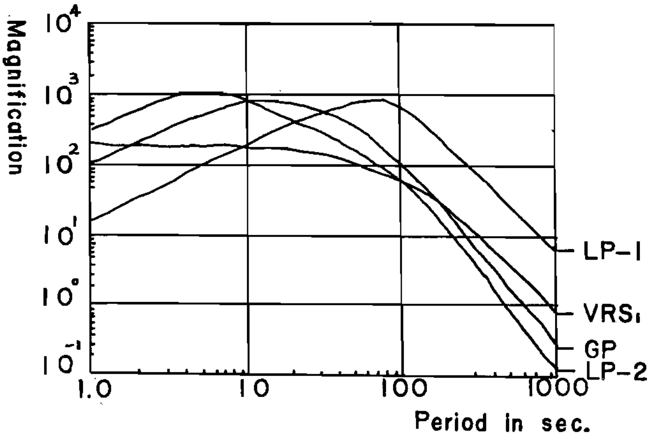


Fig. 2. Magnification curves of long-period seismographs.
LP-1 ; $T_0=180$ sec., $h_0=1$, $T_g=100$ sec., $h_g=1$
LP-2 ; $T_0=6$ sec., $h_0=1$, $T_g=100$ sec., $h_g=1$
GP ; Ewing-Press long-period moving-conductor electro-magnetic seismograph, $T_0=15$ sec., $h_0=1$, $T_g=70$ sec., $h_g=1$.
VRS ; Benioff electromagnetic linear strain seismograph, $T_g=70$ sec., $h_g=1$.

of inertia and period, and maintaining its stability, as seen in Fig. 1. The period is depended on the tilt of the apparatus, and is not over 240 sec. for the apparatus to be used with stability. Thus the observation had been carried out in the condition of period of 180 sec. A sensitive galvanometer, having 100 sec. in period, is directly connected with the LP-1 seismograph. The constants of this system are shown in Table 2 and the magnification curve is in Fig. 2. A seismograph of Galitzin B-type, as noted by LP-2, designed by Sassa was used for comparison with the LP-1 and the magnification curve of the former shown in Fig. 2, too.

The pendulum part of the system was set on the base of vertical tunnel near the Laboratory, of which the depth is about 16 m.. The base is lava coated with concrete. The entrance of tunnel was covered with soil and attached with three doors for the inside of tunnel to be tripply isolated from outside. It is away from as much of unfavorable effects of temperature or wind as possible. The pendulum part was set to record E-W component, since the volcanic micro-tremors of the 2nd kind are predominant in the

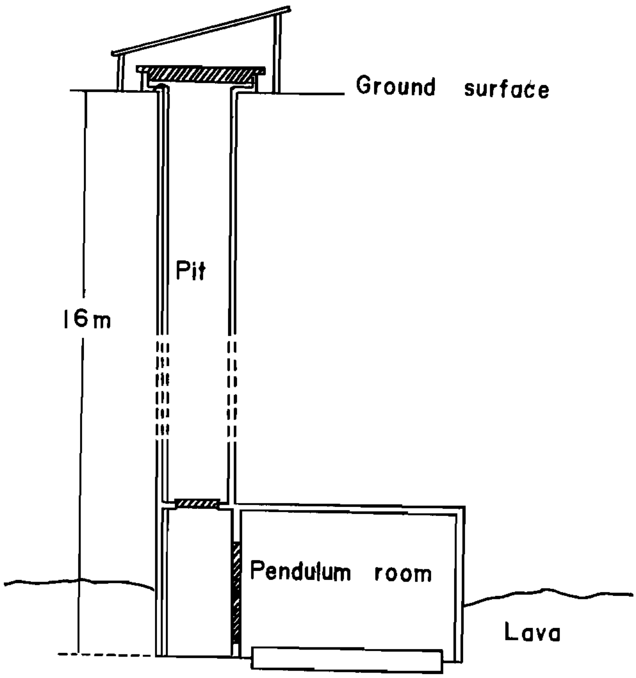


Fig. 3. Equipment of underground pendulum room.

same component. Fig. 3 shows a section of the tunnel.

3. Observation

3.1. The Alaskan Earthquake of Apr., 7, 1958

By LP-1 seismograph the Alaskan Earthquake[7] of Apr., 7, 1958 was recorded. The epicentral distance is 52°, and the azimuth is N28°01′E. The great circle between the observing station and the epicenter is shown in Fig. 4. Unfortunately another shock occured in the Pacific Ocean near

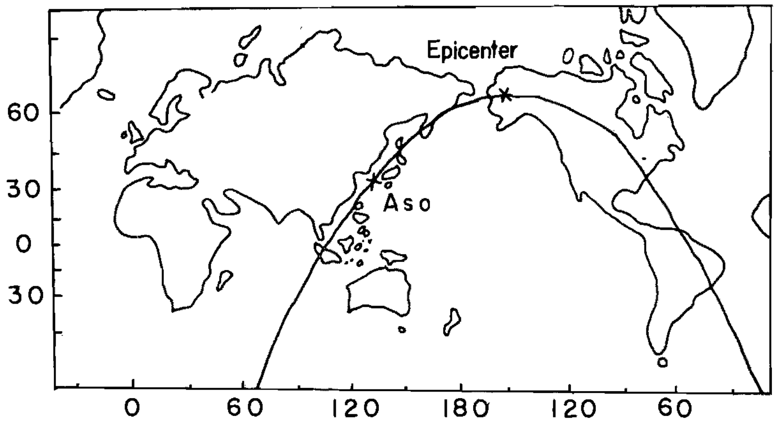


Fig. 4. Great-circle path from the epicenter to Aso of the Alaskan earthquake of April, 7, 1958.

Japan and disturbed the record. As shown in Fig. 5, some of long-period surface waves were recorded. Among them, the comparative clear phases are regarded as G_1, G_2 and R_2-phases. Their arrival time, period, travel time and velocities are listed in Table 3. The group velocity of R_2-wave is plotted in comparison with the dispersion curve and those obtained by Ewing and Press[8], as shown in Fig. 6.

3.2. The ground noise

The ground noise of short period is not so predominant to disturb our purpose, at most 0.1 μ in amplitude, since the observing station is remote in about 2 km. from the nearest railway and highway. Thus the ground noise recorded on the seismogram is usually of long period. Examining the meteological condition, this ground noise is likely to be accompanied with

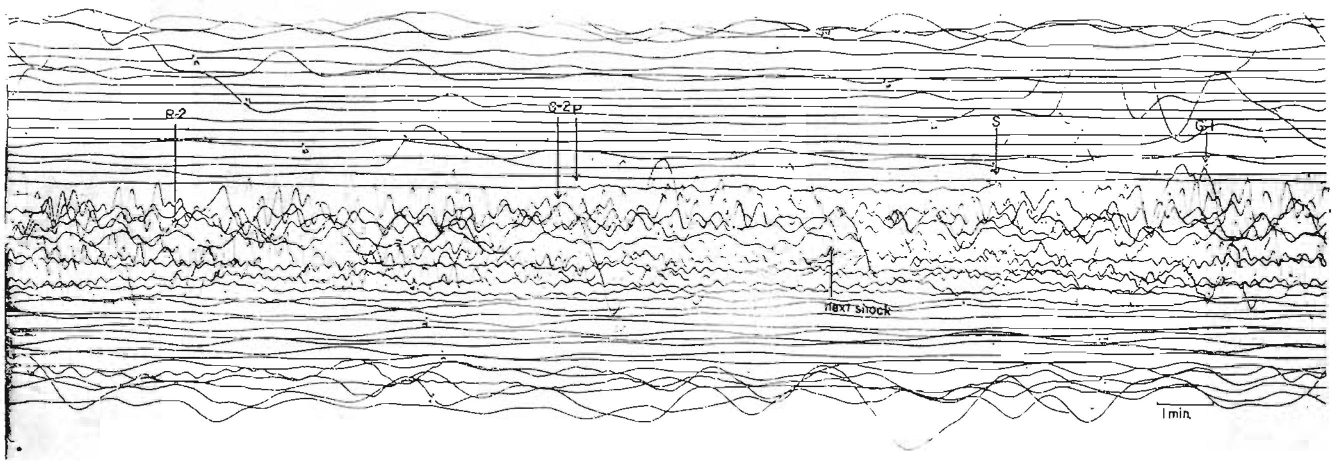


Fig. 5. Long-period seismogram (E-W) of Alaskan earthquake on April, 7, 1958, showing long-period waves.

Table 3. Arrival time, period, travel time, and velocity for long-period waves of the Alaskan earthquake of April 7, 1958.

Arrival time	Period in sec.	Travel time in sec.	Velocity km/sec.
$\Delta_1=6003.8$ km			
00 : 51 : 23.4	76.0	1255.9	4.78
$\Delta_2=34011.8$ km			
02 : 57 : 09.8 03 : 02 : 34.4	102.6 182.2	8793.3 9117.9	3.87 3.73

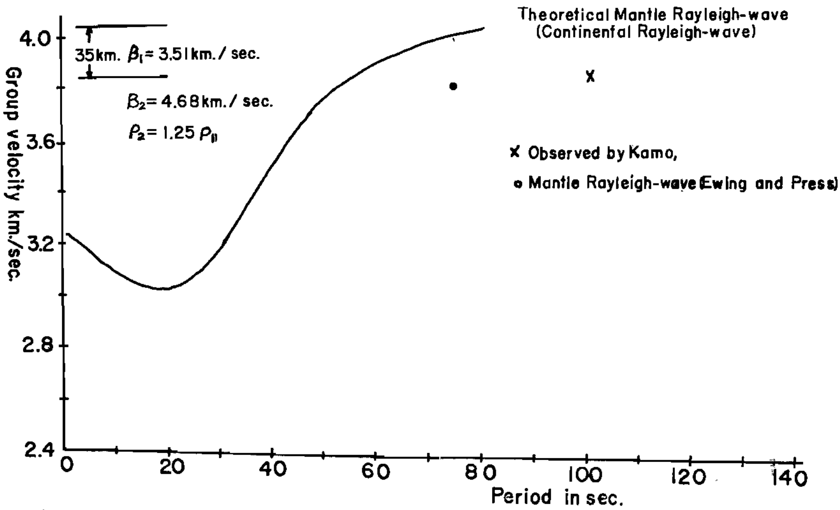


Fig. 6. Observed and theoretical dispersion of continental Rayleigh waves (after Ewing and Press).

wind at the observing station. To find correlation between wind speed and amplitude or period of ground noise, an example of the correlations are shown in Fig. 7. The amplitude and period vary almost linearly with the variation of wind speed. When the wind speed is over 5 m./sec., the amplitude amounts to about 10 μ. and the period amounts to 40 sec., or more, sometimes 90 sec. in windy day. Thus when it is windy, the observation is difficult, or almost impossible. (a) and (b) of Fig. 8 are examples of the records obtained on windy and calm conditions, respectively. The dependences of amplitude and period on wind speed are shown in Fig. 9 and 10.

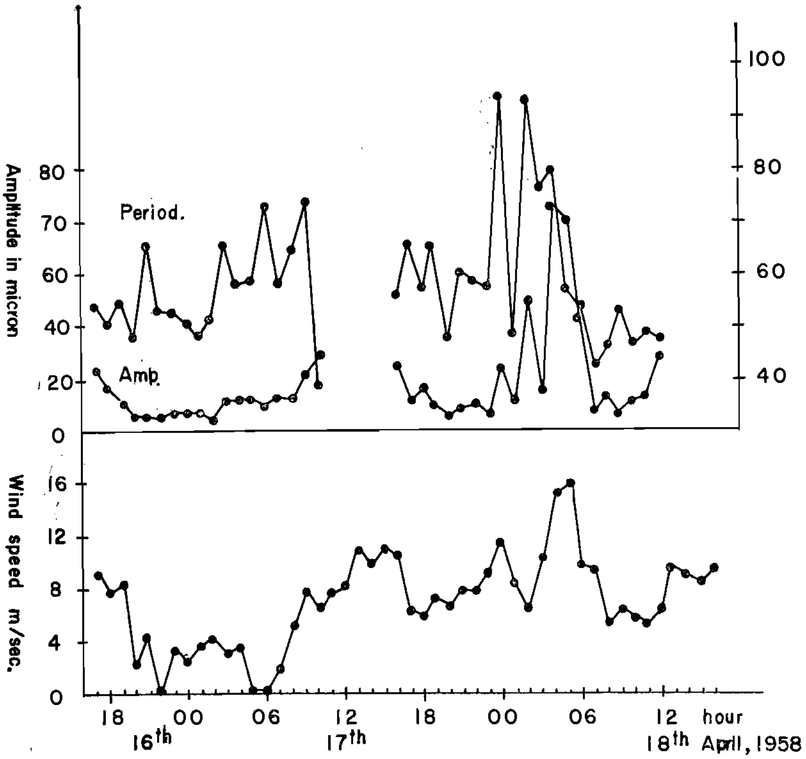
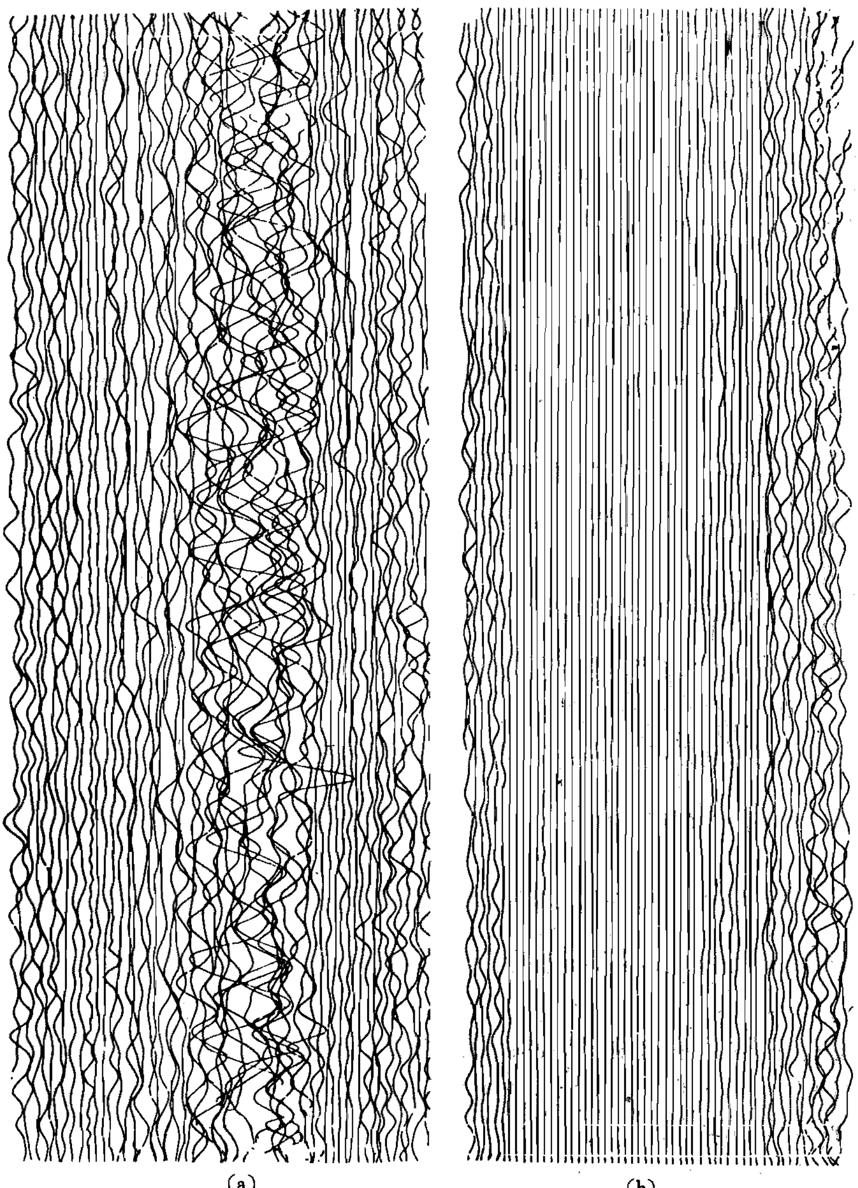


Fig. 7. Amplitude and period of the tremors caused by wind, and wind speed on 16, 17, 18, April, 1958, at the Aso Volcanological Laboratory.

3.3. Long-period volcanic micro-tremors

As mentioned above, the LP-1 seismograph may be thought available for our purpose. In fact, when the eruption of the 1st crater of the Volcano Aso on July, 24, 1958, took place, the long-period micro-tremors, amounty to 40~55 sec., were recorded. Examining the records we can point out the followings: the amplitude is frequently over 10 μ.. This tremor is usually composed of about four pairs of crest and trough and occurs discontinuously. As an eruption approaches, the number of crest and trough increases and the appearance is almost continuous with regular sinusoidal form of wave. Their disappearance on record begines at about an hour preceding an eruption. This conspicuous tendency is clearly found in Fig. 11 and 12. Moreover, the period is about 40 sec. in the initial stage of the appearance, but increases to 55 sec. before an eruption. To



(a) (b)

Fig. 8. (a) A record registered by LP-1 seismograph on April, 17~18, 1958, windy days. attenuator used=1/2, time between two consecutive marks=1 miunte, 1/3.8×the original record. LP-1 ; T_0=180 sec., h_0=1, T_g=100 sec., h_g=1.

(b) A record registered by LP-1 seismograph on April, 19~20, 1958, calm days. attenuator used=1/2, time between consecutive marks =1 minute, 1/3.8×the original record.

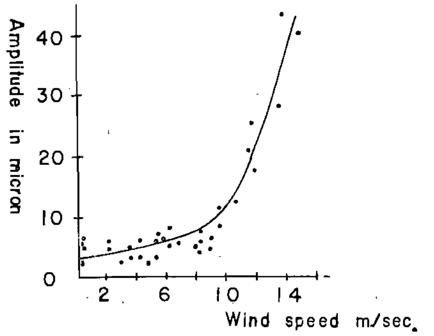


Fig. 9. Wind speed and amplitude of tremors caused by wind.

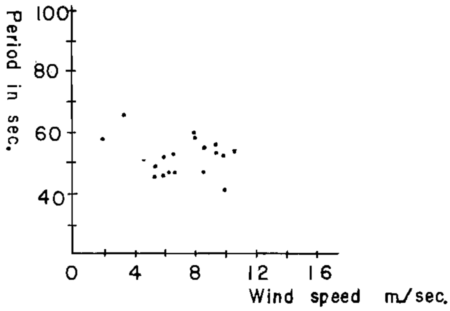


Fig. 10. Wind speed and period of mors caused by wind.

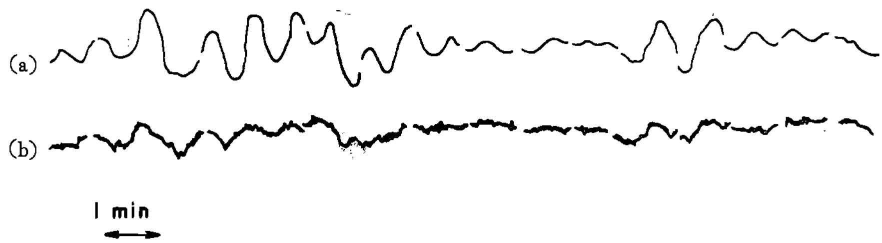


Fig. 11. Comparison of the tracings of LP-1 and LP-2 seismogram before the great eruption on June, 24, 1958.
(a) Tracing of LP-1 seismogram
(b) Tracing of LP-2 seismogram
Note : Long-period tremors are recorded in the both trace, and the 2nd volcanic micro-tremors are only in the tracing of LP-2 seismogram.

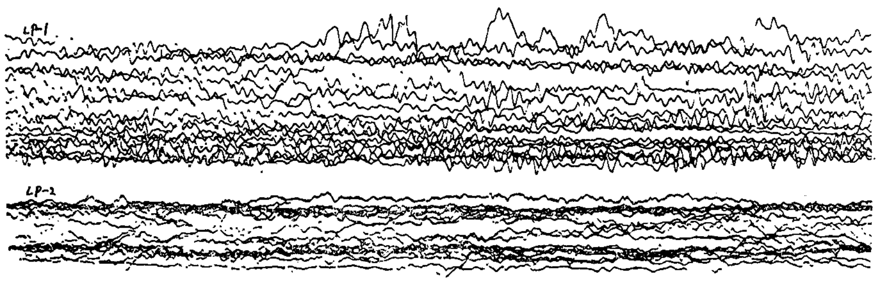


Fig. 12. (a) A record registered by LP-1 and LP-2 seismograph on June, 23~24, 1958.
Attenuator used=1/2, drum speed=0.97 cm/min., 1/5.5×the original record.
LP-1 : T_0=180 sec., h_0=1, T_g=100 sec., h_g=1
LP-2 : T_0=6 sec., h_0=1, T_g=100 sec., h_g=1.

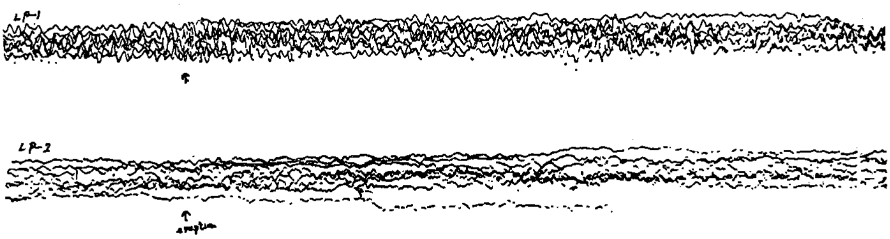


Fig. 12. (b) A record registered by LP-1 and LP-2 seismograph on June, 24, 1958, continued from Fig. 12 (a).
Attenuator used=1/2, drum speed=0.97 cm/sec, 1/5.5×original record.
LP-1 : T_0=180 sec., h_0=1, T_g=100 sec., h_g=1
LP-2 : T_0=6 sec., h_0=1, T_g=100 sec., h_g=1.

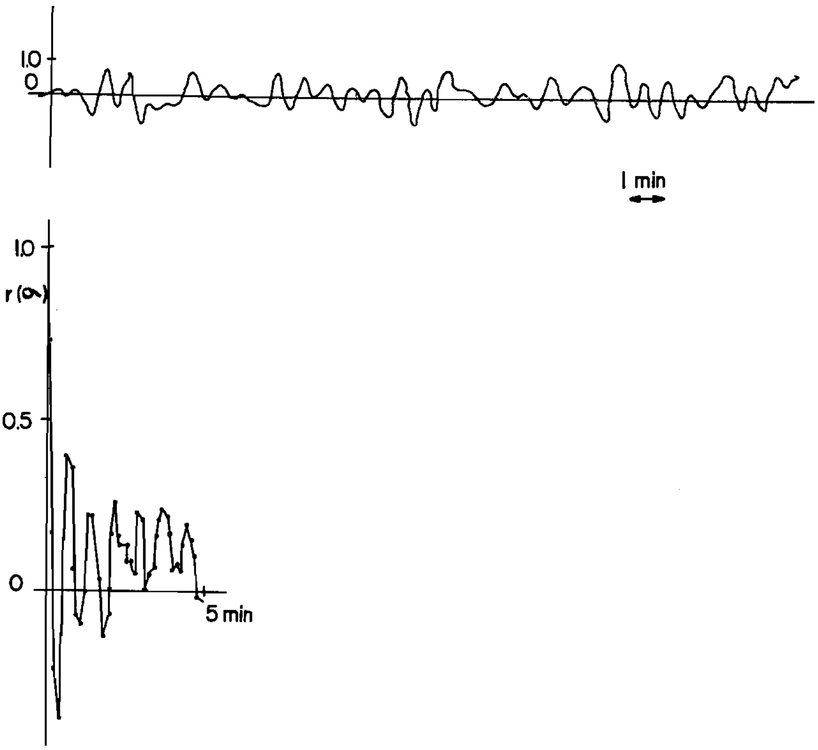


Fig. 13. (a) Tracing of LP-1 seismogram on June, 24, 1958, at the initial stage of appearence.
(b) Correlogram deduced by Tomoda's method.

show this fact clearly, auto-correlation is applied by Tomoda's method[9] It is resulted that the period varies from 42.4 sec. in the initial stage to 49.6 sec. befor an eruption, as shown in Fig. 13 and 14.

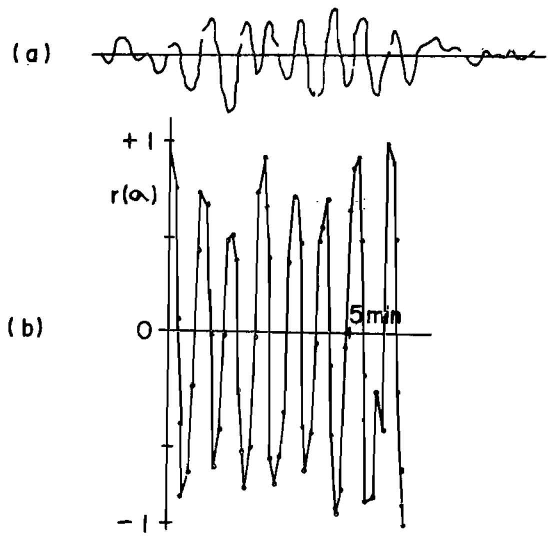


Fig. 14. (a) Tracing of the LP-1 seismogram before the eruption on June, 24, 1958.
(b) Correlogram.

The relation of the variation of the long-period volcanic micro-tremors with volcanic activity, as described above, may be compared with those of the other kind of tremors pointed out by Sassa[10]. Then the variations of mean amplitude and period of tremors of each kind are plotted in Fig. 15 during Apr., May and July of 1958, where the volcanic micro-tremors of the 1st and 2nd kinds are taken from the records of Wiechert-seismographs at the Volcanological Laboratory. The

Micro-tremors of 1st kind observed by Wiechert seismograph

Micro-tremors of 2nd kind observed by Wiechert seismograph

Long-period tremors observed by LP-2

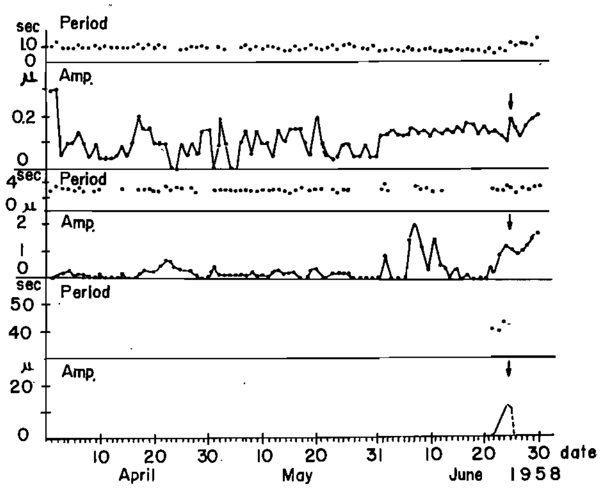


Fig. 15. Mean amplitude and period through April, May and June, 1958 (arrow indicates the great eruption).

long-period tremors appeared first on July, 22, corresponding to the increase of the volcanic micro-tremors of the 2nd kind, and after the eruption, though the observation was interrupted due to an accidental stoppage of electric current caused by the eruption, the tremors are not found at least on the 25th and the disappearance continued through July. On the other hand, the more minute variations from July, 23 to the eruption are shown in Fig. 16, with those of the volcanic micro-tremors of the 3rd kind

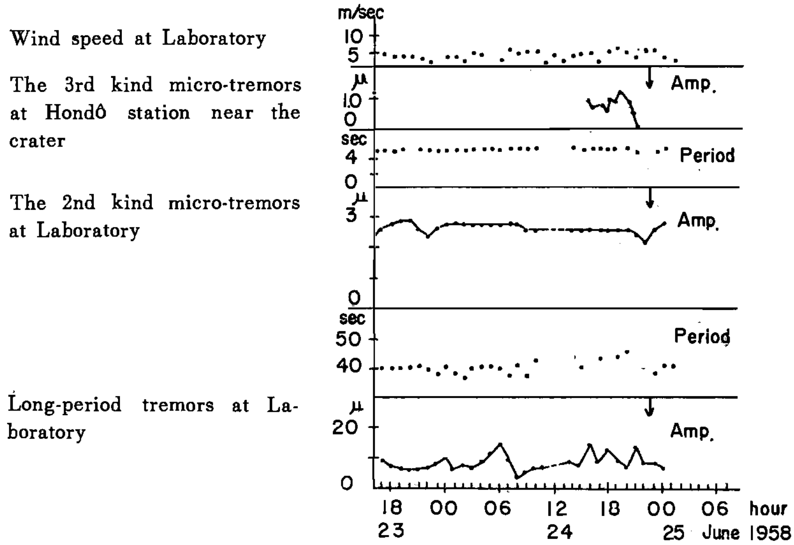


Fig. 16. Mean amplitude and period, per hour, of volcanic micro-tremors before the great eruption on June, 24, 1958 (arrow indicates the great eruption).

observed at Hondô observing room near the crater by a high sensitive seismograph (this value was deduced only from the data in night, since in daytime the rope-way disturbed the observation). And also those of the 2nd kind and the mean wind speed per hour are together plotted there.

The long-period tremors begin to appear when the amplitude of the volcanic micro-tremors of the 2nd kind are large, and the amplitude of the former appears to decrease before an eruption in the similar tendency as that of the volcanic micro-tremors of the 1st and 2nd kind. The long-period micro-tremors can be discriminated from the ground noise by considering the wave forms of both, that is, the ground noise does not occure in regular sinusoidal form.

Though the observation was carried out in single component alone, the expectation that the wave type may be same as that of the volcanic micro-tremors of the 2nd kind is not always unreasonable. At any rate, it may be noted that there is a close relation between the occurrence of long-period tremors and that of tremors of the 2nd kind.

4. Conclusion

The existence of a new type of volcanic micro-tremors, having the period of 40∼55 sec. and accompanied with volcanic activity, was detected by carring out the observation at the Volcano Aso with long-period seismograph. This tremore appears to be related closely with volcanic activity in the similar tendency as the volcanic micro-tremors of the 2nd kind, as pointed by Sassa.

The type of the wave and the propagation velocity, however, are not yet determined, since the observation was carried out only in E–W component. These problems will be resolved near future by carring out observation with several seismographs.

5. Acknowledgment

Much of this work was suggested by Professor Kenzo Sassa of Kyoto University, to whom the writer owes for his interest and encouragement. The writer wishes to express his thanks to Dr. Kennosuke Okano of the Abuyama Seismological Observatory of Kyoto University for his many advices, and is greatly indebted to Mr. Toshiji Eto for the observation.

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