8. Geophysical Studies of Volcano Mihara, Oosima Island. III.

Microtremor Measurements in Oosima.

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1. Introduction.

Although in the previous papers,[1] the writers stated that volcano Mihara[2] was calm then and likely to remain so for a while, rumblings, small explosions, and volcanic tremors never cease even in this calm period. For the purpose of recording the variations in the amplitude of the volcanic tremors, which serve as a measure of this volcano's activity, a microseismograph of magnification 400 was installed on February 1936, at Gozinka-tyaya,[3] on the western summit of the somma. Similar seismographs were installed later (August 1937) at Sendu,[4] the northern coast of Oosima, and at Sasikidi,[5] the south-eastern coast. Since then, continuous observations of the volcanic tremors and earthquakes were carried out by means of these seismographs.

The micro-tremors that were observed at Gozinka-tyaya were of the order of several microns in amplitude, without any marked correlation with the speed and direction of the wind. They vary incessantly in amplitude, no distinct regularity having been noticed in the manner of their growth and decay. These features, however, are those that are apparent in a period of calm, such as the present. In a more active period, the tremors may have very large amplitude, as has been reported by F. Omori[6]; or an intimate relation may be found to exist between their growth and decay and the activity of the volcano, as observed by K. Sassa[7] at Aso.

When F. Omori,[6] in 1912, observed micro-tremors at several points in Oosima, he found that the tremors east of Kagamihata,[8] the highest

1) *Bull. Earthq. Res, Inst.*, **15** (1937), 441, 1047.
2) 三原， 3) 御神火茶屋， 4) 泉津， 5) 差木地， 8) 鏡端.
6) *Rep. Earthq. Inv. Comm.*, No. 81, (1915).
7) *Mem. Coll. Sci. Kyôto Imp. Univ. Ser. A* **18** (1935), No. 5; **19** (1936), No. 1.

peak in the western somma, have larger amplitudes than those observed on the western slope of the central cone; also that the tremors at Motomura[9] are only one-third the amplitude of those observed at Kagamihata. The result was the same in the case of the tremors observed at Yuba,[10] the distance of which from Kagamihata is the same as that of Motomura. These results led him to conclude that the source of the tremors is not immediately beneath the crater, but at a point from 500 to 600 m beneath Kagamihata.

Since to ascertain the origin of the tremors is one of the pressing needs in the study of the volcano, the writers made observations of micro-tremors at 19 stations in Oosima, using a portable microseismograph of magnification 2000.

2. Instrument.

The seismograph used in these observations was the inverted pendulum seismograph[11] designed by M. Ishimoto. For portability, the oil damper used in the original pattern of this seismograph was replaced by an air damper. The improved pattern of this instrument is fitted also with a device for obtaining three changes in magnification, namely, 500, 1000, and 2000. When damped almost critically, the period of proper oscillations is 2·0 sec. Since none of the micro-tremors involved have periods exceeding a second, this seismograph is admirably suited for the present purpose. The records were obtained optically on bromide paper wound on a drum, revolving with sufficient uniformity, the length of the record always corresponding to 3 minutes within an error of 0·5 mm.

It was therefore easy to measure the periods of the tremors with an accuracy of 0·01 sec. The bromide paper recorded for 3 minutes.

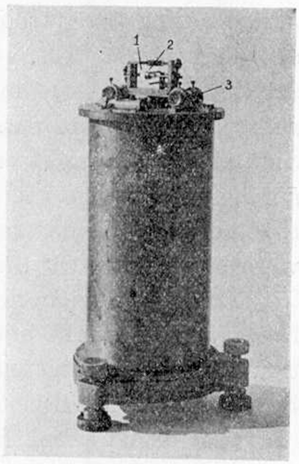


Fig. 1. Seismograph used in the present measurements.
1. Mirror
2. Roller
3. Air damper

3. Stations and Observations.

Since the topography of the island made it impossible to distribute

9) 元村， 10) 湯場.
11) *Bull. Earthq. Res. Inst.*, 1 (1926), 1.

our 19 stations uniformly there, they were distributed as shown in Fig. 2, namely, 7 on the route from Motomura to the crater, 2 on the rim of the central cone, and the remaining 10 as uniformly as possible over the island.

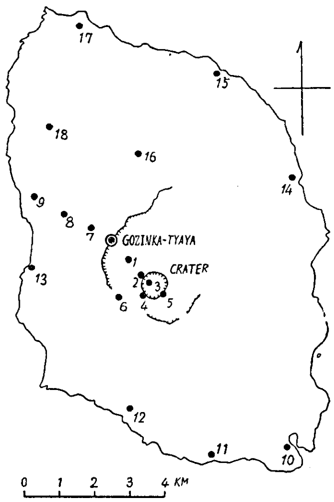


Fig. 2. Distribution of stations. Numerals indicate Station Nos.

The seismograph at every station was installed directly on the ground. To avoid the effect of winds, the observations were made at points as far as possible from big trees and houses. In the present measurements, only the horizontal component of the tremors was observed. Since for ease of transport, only one seismograph was used, the component *"station-crater"* was first observed, followed immediately by observations of the component perpendicular to it. Observation at a station usually consisted of taking two records for each of the two components. The instants of beginning and ending of a record were carefully noted for comparison with the continuous observations at Gozinka-tyaya.

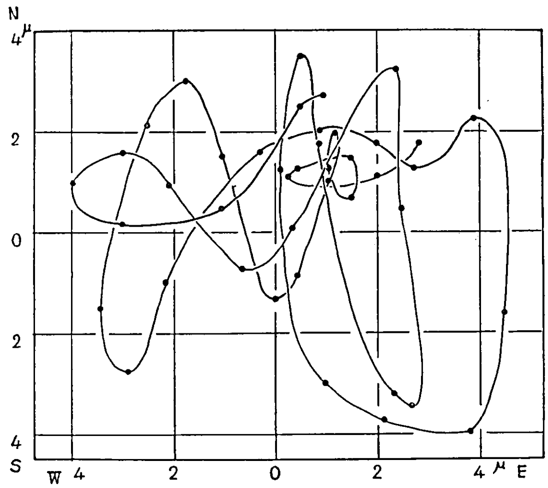
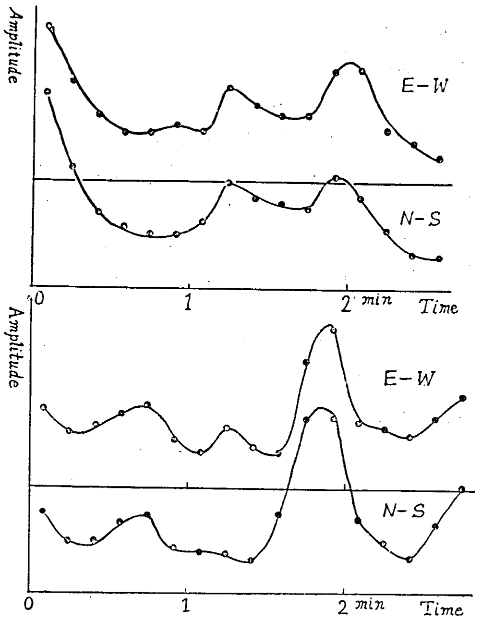


Fig. 3. The combined motion of the ground as observed at Gozinka-tyaya.

The character of the tremors at Gozinka-tyaya was studied as the first step in this investigation, using two identical microseismographs at the same time. The two seismographs were installed in directions at right angles to each other. The combined horizontal motion of the ground thus obtained, which is shown in Fig. 3, is very irregular in shape, with no pronounced direction of oscillation; that is, when the oscillation is vigorous, the amplitude is large in all directions and *vice versa.* Moreover as plotted in the manner shown below, the growth and decay of the two components are nearly parallel as shown in Figs. 4a, 4b.

When this character of the oscillation of the tremors, as shown below, obtains at other stations as well, we may then ignore altogether the question of the dominant direction of the oscillations in the present investigation. The fact cited above may thus be interpreted as justifying the method used at the other stations, where the two components are not observed simultaneously.



Figs. 4a, 4b. Parallelism in the growth and decay of the two horizontal components.

Since the variation in the amplitude of the tremors usually amounts to 50 percent, when we speak of distribution, the amplitude of the tremors as measured at each station must be compared with simultaneous observations made at some standard station, for which we selected the microseismograph of magnification 400 installed at Gozinka-tyaya.

In these circumstances, strict agreement in time between the field stations and the standard station was difficult to attain, there being a discrepancy of probably several seconds, as the result of which it was impossible to investigate the phases, so that all the measured amplitude must be discussed only with reference to their mean values with regard to time.

4. Results of the Measurement.

In Figs. 5a∼5c Pl. III∼V, are shown a number of records thus obtained at the various stations. As will clearly be seen from these figures, some of the curves show merely simple harmonic oscillations of varying amplitudes, while others are composed of several harmonic oscillations of different periods, or are quite irregular.

There are at least three possible causes of these tremors. They are either propagated from a common source, or they are free oscillations of the superficial layer of the ground induced by the former cause; or they may be forced oscillations. Volcanicity is not necessarily the cause of these tremors; the sea waves and winds may induce these tremors exactly as in the case of common pulsations. Consequently, in order to determine the cause of the tremors, it is necessary to make simultaneous observations, using one vertical and two horizontal component seismographs. The relations between the phases of the oscillations will also have to be investigated at the different stations; that is, we must ascertain what sort of elastic waves the tremors consists of.

When tremors of a definite period appear at all the stations, we naturally conclude that they were propagated from a common source. With these meanings, we made the following frequency analysis. The time intervals between each successive instant $\dot{x}=0$, where x is the displacement, were read off from each record, and a frequency curve was drawn as shown in Fig. 6. According to necessity, the same process was repeated with the smoothed curves, in which the oscillations of shorter period were eliminated by joining the middle points of successive $\dot{x}=0$'s. The process then gives the oscillations of long periods.

A number of frequency curves thus obtained are shown in Fig. 6, a and b. If there are two curves in a diagram, they correspond to the original and the smoothed records respectively.

Fig. 7 shows the predominant periods at the various stations. As will be seen from this figure, oscillations of period 0·32∼0·30 sec. appear at all the stations, except one. Moreover, at such stations as No. 7 and No. 8, where the tremors have only a single period, the period is 0·32∼0·30 sec., without exception. It will also be noticed that, at the central cone, the tremor is composed of several oscillations of different periods, while at the slope of the somma the tremor is comparatively simple, although there are of course several exceptions to this rule. For example, at stations Nos. 14 and 15 there are oscillations of such short periods as 0·15 and 0·20 sec., while at stations, Nos. 10, 12, 13 (all coastal stations), we find irregular oscillations of long periods. These exceptional oscillations however occur only in one of the two components, as shown in Fig. 5, Pl. III∼V., whereas the oscillation of period 0·32∼0·30 sec. appears in both components.

From these facts, it may be said that tremors, which are composed of oscillations of different periods at the central cone, become simple oscillations with increased distance from the central cone, and again become irregular at the coast.

Since owing to a storm at the time, the measurement were made indoors at stations Nos. 14, 15, the short period oscillations observed there are probably those of the station houses. The irregular oscilla-

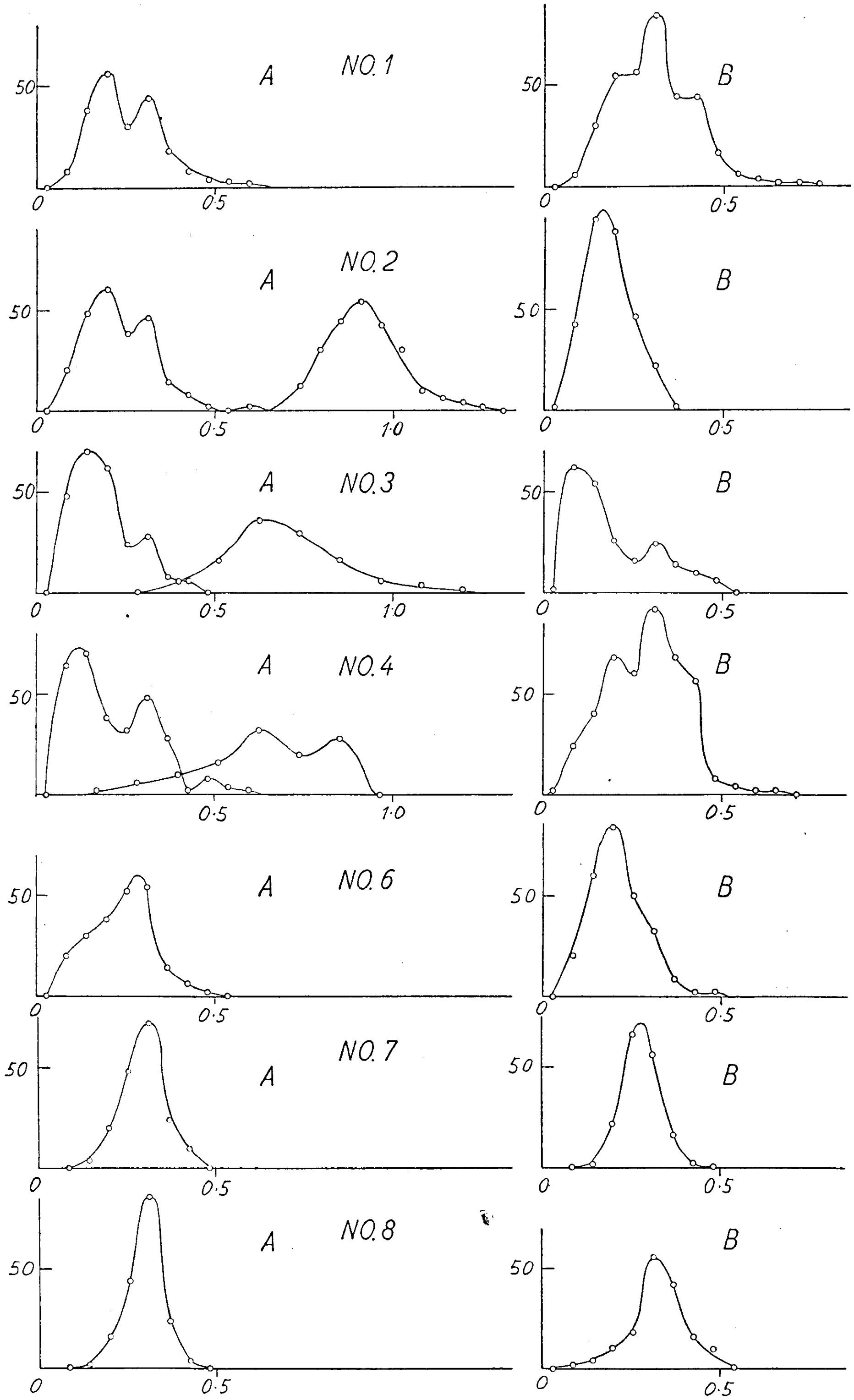


Fig. 6a. Frequency curves of the periods of tremors observed at the various stations. B. The component in the direction of the crater. A. The component that is perpendicular to B.

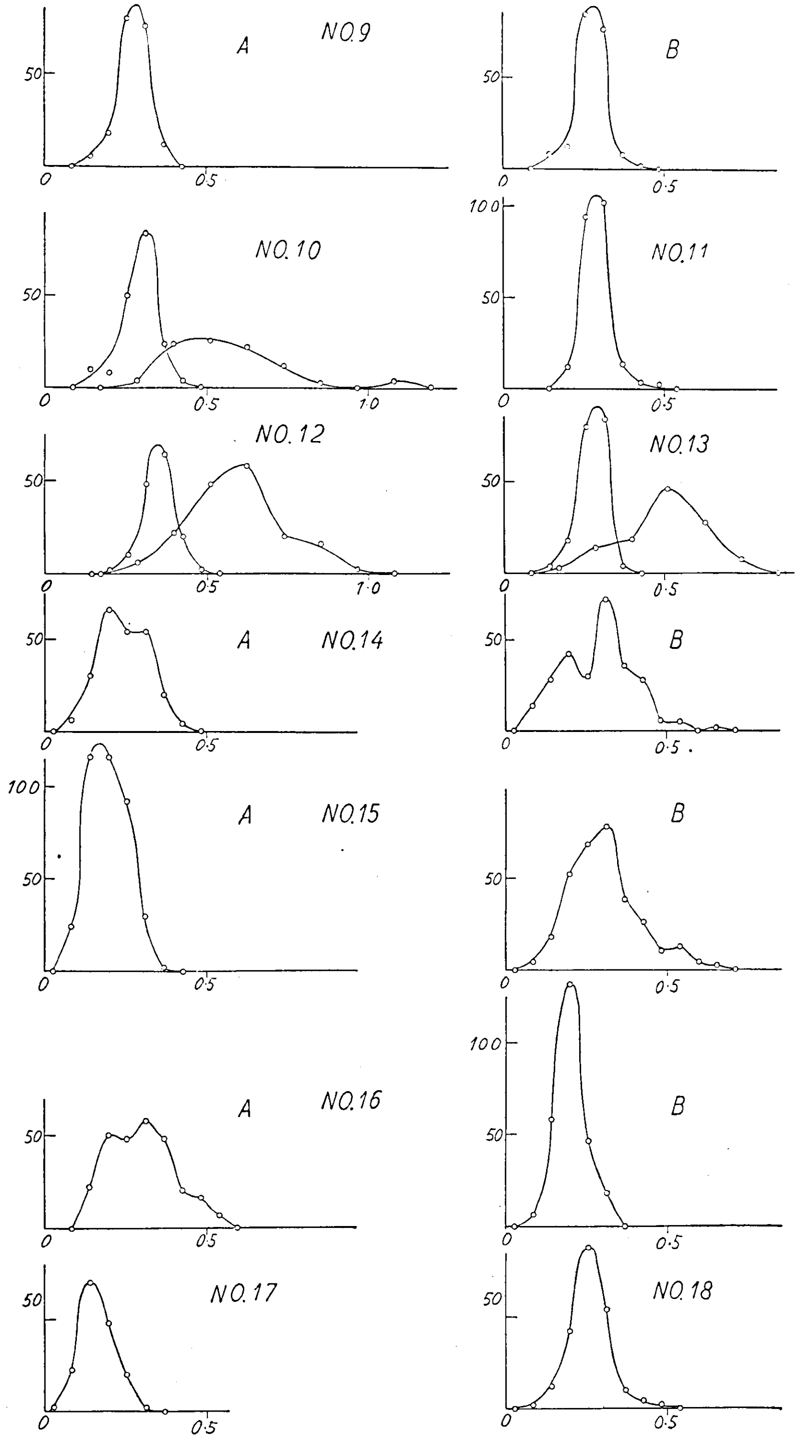


Fig. 6b. Frequency curves of the periods of tremors observed at the various stations. B. The component in the direction of the crater. A. The component that is perpendicular to B.

tions that were observed at stations Nos. 9, 10, 11, 12, 13, 16, 17 appeared only in the direction indicated by the bars in Fig. 8. Except No. 16, all these stations lie near the western coast of Oosima.

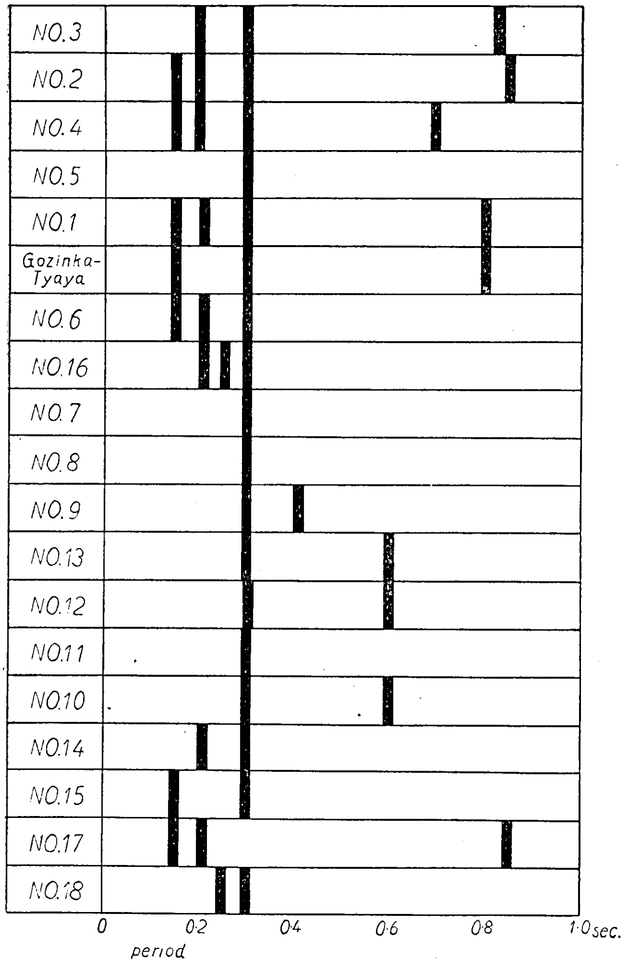


Fig. 7. Predominant periods at the 19 station.

Since during these measurements, the wind was blowing at the rate of 5~10 m/sec from the west, it is highly probable that these irregular oscillations are due to sea waves, although their mechanism of generation is not simple, seeing that they appear only in a direction parallel to the coast.

Since the tremors undergo incessant growth and decay, in order to ascertain the distribution of the amplitudes of the tremors in Oosima, the amplitude of the tremor must be compared with that of the tremor that is continuously observed at Gozinka-tyaya, the standard station. As already stated, this comparison is not one of phases. But since the period of growth and decay of the tremor is from 2 to 4 sec., we can take as a measure of variation in the amplitude of the tremors the curve obtained by plotting the maximum amplitude during the successive periods of growth and decay. The curve thus obtained may afford a means of comparing the field record with the standard at Gozinka-tyaya.

Actually, we plotted the maximum amplitudes for every 10 seconds against the time. As shown in Fig. 9, a and b, this simplified method yields practically the same result as the former, in which the maximum amplitude of each wave group was plotted. It is therefore sufficient for the present purpose.

The standard microseismograph installed at Gozinka-tyaya records only the component that is parallel to the direction of the crater. Since, however, the growth and decay of the tremor is practically the same for the two components that are perpendicular to each other, as already shown in Figs. 4, a and b, it will be quite in

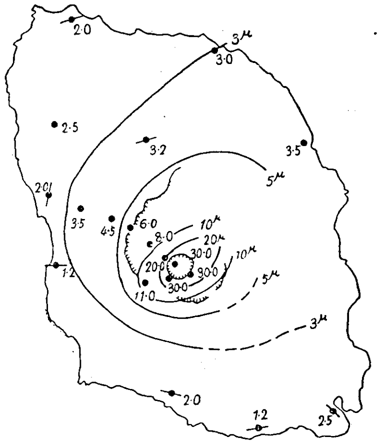


Fig. 8. Directions in which irregular oscillations appear and the distribution of the amplitudes of the tremors in Oosima.

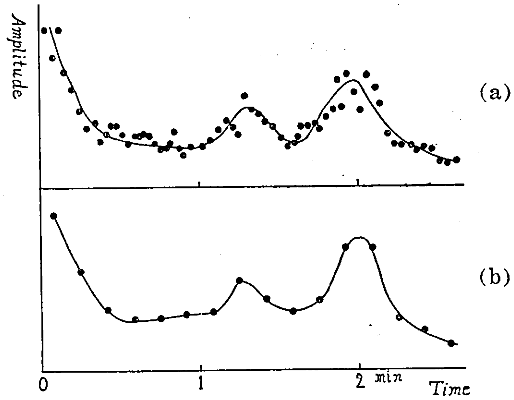


Fig. 9a. (a) Maximum amplitudes of successive wave groups.
(b) Maximum amplitudes every 10 sec.

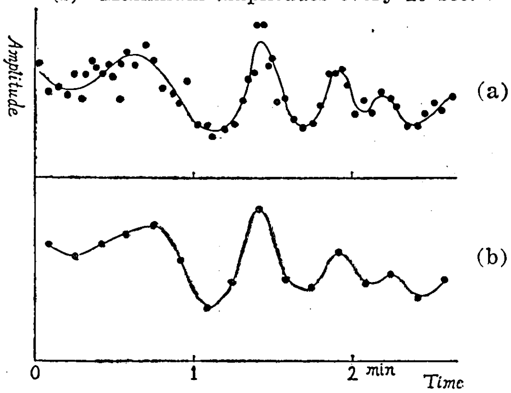


Fig. 9b. (a) Maximum amplitudes of successive wave groups.
(b) Maximum amplitudes every 10 sec.

order to compare the field observation made in an arbitrary direction with that by the standard seismograph installed in a particular direction.

If treated as described above, the tremors observed at some of the stations show, as in Fig. 10, nearly the same manner of growth and decay as those at the standard station, while those observed at other stations show, as in Fig. 11, no remarkable correlation. In the latter case, we took the ratio of the mean amplitudes for 3 minutes.

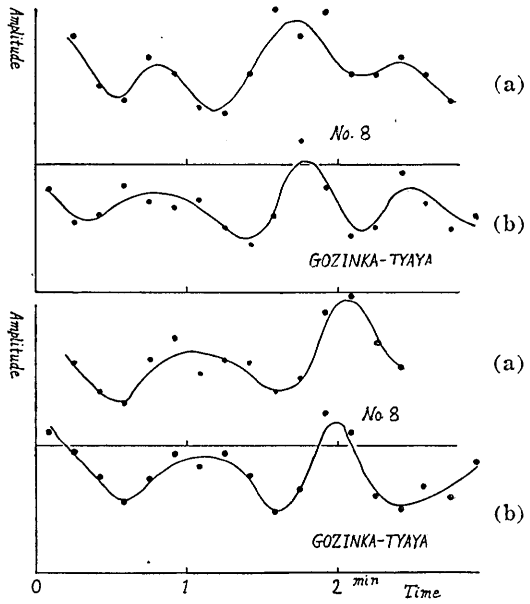


Fig. 10. Comparison of the field and standard stations.
(a) Field station.
(b) Standard station.

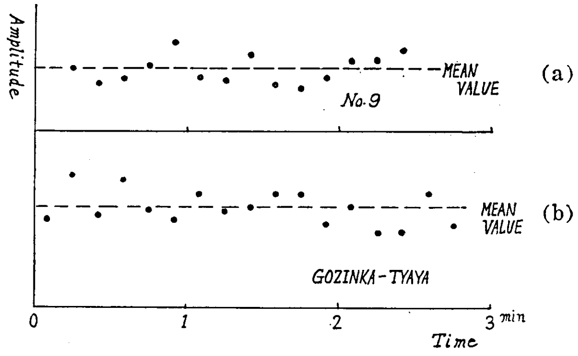


Fig. 11. Comparison of the standard and field stations.
(a) Field station.
(b) Standard station.

The amplitude of tremors thus determined are given in Fig. 8, in which the amplitude at Gozinka-tyaya, the standard station, has been taken as $5\,\mu$. Since there are no more than 19 stations, we do not expect any conclusive results from the present measurements, but the tremors seem to have the largest amplitude at the crater, gradually diminishing as one recedes from it. There seems to be no locality where the amplitude is abnormally large or small. Although this result does not necessarily refute the conclusions of F. Omori, his conclusion is at least suspect, as his measurements were not made simultaneously.

The volcanic earthquakes that shake Oosima do not always originate from underneath the present crater. In the same way, during an active period of the volcano, the source of its tremors may be situated elsewhere than the present crater, so that we cannot reject Omori's conclusion *in toto*.

Judging from the present results, the sourse of the tremors seems to lie underneath the present crater, so that we have plotted the amplitudes of the tremor that were determined in the manner stated above against the distances of the respective stations from the crater. Fig. 12, thus obtained, seems to show a hyperbolic decrease of amplitude with distance.

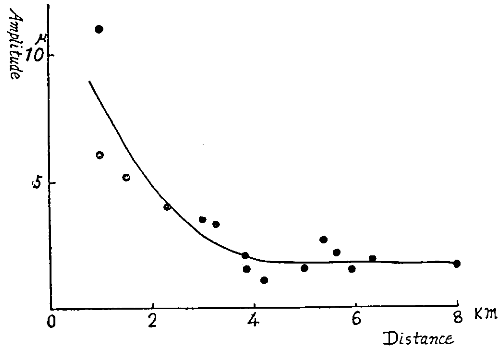


Fig. 12. Decrease in amplitude with increasing distance from the crater.

The manner in which the amplitude of the tremors diminishes with distance from the crater was carefully studied in detail, particularly with regard to the stations on the route from Motomura to the crater.

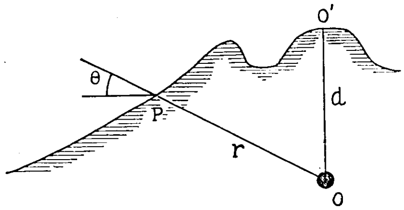


Fig. 13.

Assuming that the source of the tremors lies 400 m below the crater mouth, the measured amplitudes are inversely proportional to the hypocentral distance r of the stations, as shown in Fig. 14. Assuming now that a point sourse

$$A_0 e^{i\nu t}$$

is at the origin, the amplitude of the spherical waves that are propagated from it are given by

$$A=\frac{A_0}{4\pi r} e^{i\nu\left(t-\frac{r}{v}\right)},$$

where v is the velocity of the wave. Here amplitude A is inversely proportional to the distance r. In our case, the measured amplitude is not A, but is its horizontal component.

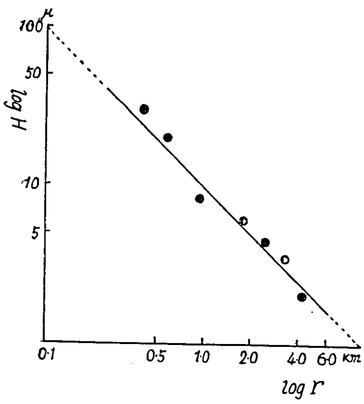


Fig. 14. Decrease in amplitude with hypocentral distance.

This seems to support the idea

that the tremors observed by us are forced oscillation of the surface layer of the ground that is in turn induced by the primary wave propagated from the origin. The excited wave will then have an amplitude proportional to the exciting wave.

It is therefore very probable that the origin of the tremors is at the bottom of the present crater, or at a point 100 m below it, at the most, and that the tremor is generated by the same cause that causes the small explosions and rumblings at the crater bottom.

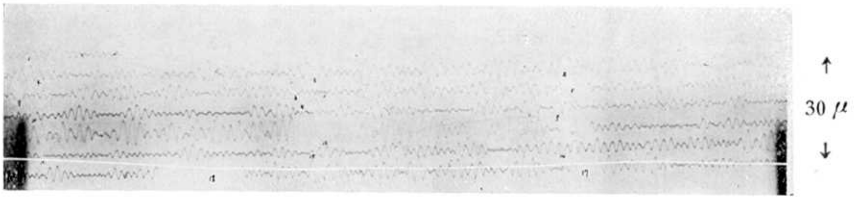
Another interesting phenomenon noticed in the course of the present measurements is that the tremor, which is nearly the same in amplitude with regard to both horizontal components at stations outside of the somma, has an amplitude nearly twice as large in direction towards the crater as that in direction perpendicular to the former at stations within the somma, especially on the central cone. We cannot tell from the present measurements, however, whether this phenomenon is due to some independent oscillation of the central cone, or to the gradual excitation of the transverse oscillation by the wave generated originally as a longitudinal wave from the crater bottom.

5. Conclusion.

These outlines of the nature of the tremors in Oosima are the result of our studies of the present measurements described above. Generally speaking, tremors of period 0·32~0·30 sec. are generated at the crater bottom in the form of longitudinal waves, whence they are propagated to the whole island of Oosima.

In view of these charactistics of the tremors, we constructed a microseismograph that records directly the growth and decay of the volcanic tremors. This instrument is an inverted pendulum type seismograph, almost identical in form with those used in the present measurements, and having an oscillation period of 0·3 sec, but without any damper. With this instrument we hope to get a large magnification through resonance with the tremors. The record is made on smoked paper wound on a drum that revolves once a week. In Fig. 15, Pl. VI, is a reproduction of a record obtained by this seismograph, which shows well the growth and decay of the tremors.

Since our measurements were made with a portable microseismograph with a proper oscillation period of 2·0 sec., and since there are 3 station seismographs of magnification 400 and a proper oscillation period of 1·0 sec., the measurement are good only for waves with periods of less than 1·0 sec. We cannot, however, know anything about



Gozinka-tyaya

No. 3.

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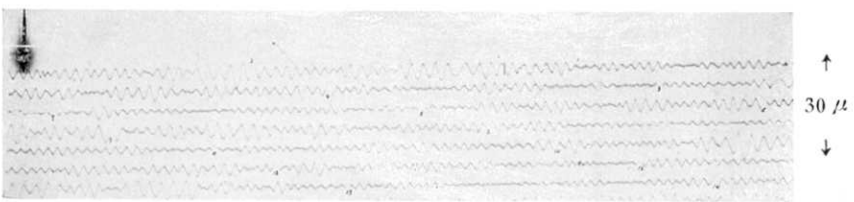

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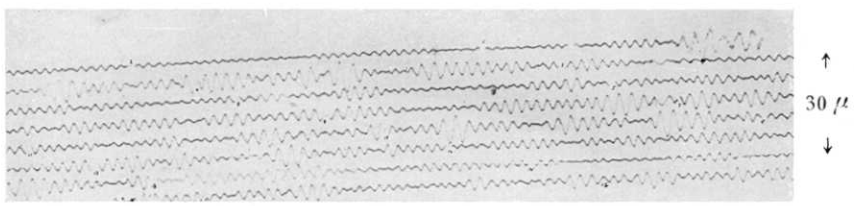

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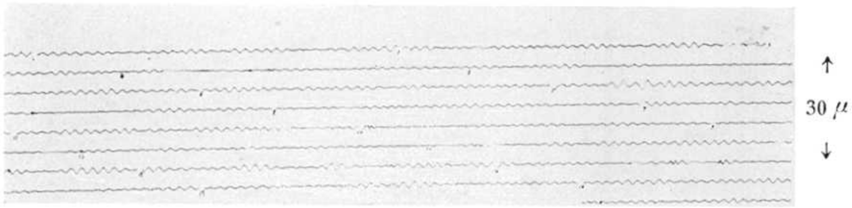
Fig. 5a. Records of tremors observed at the various stations. In the figure, 44 mm corresponds to 10 sec.



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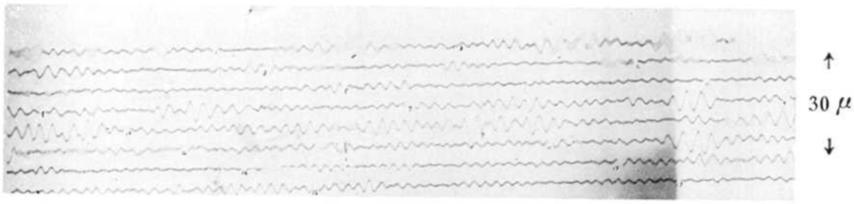

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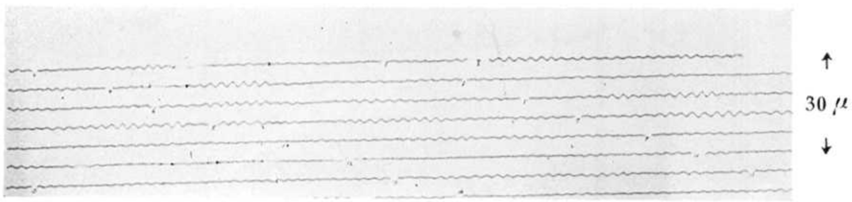

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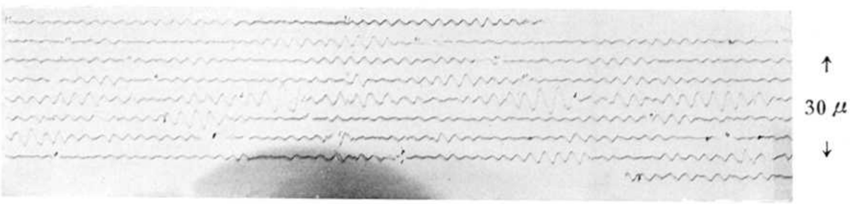

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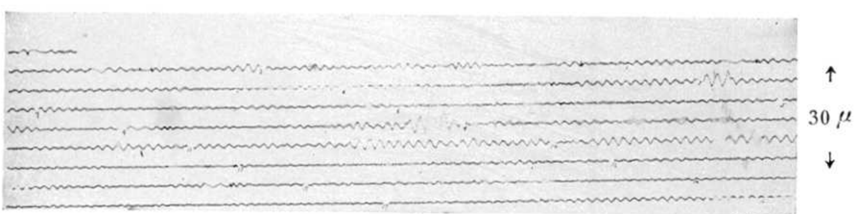

No. 13.

Fig. 5b. Ditto.

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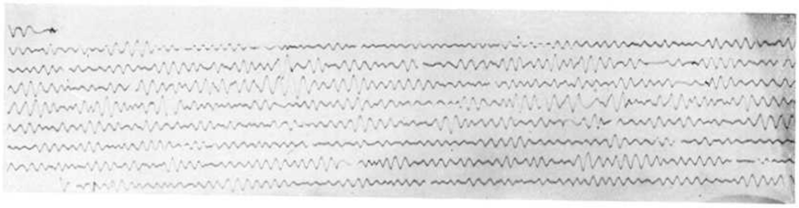
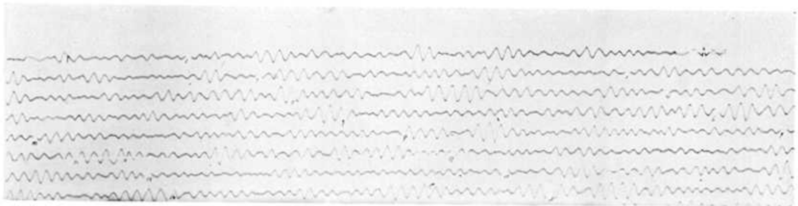


↑ 30 μ ↓

No. 14.



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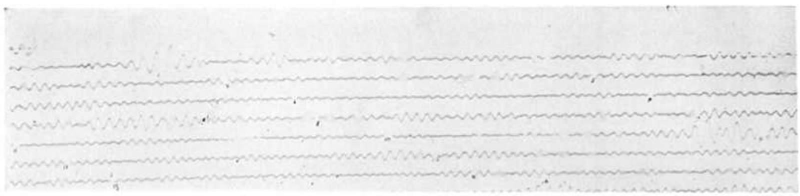

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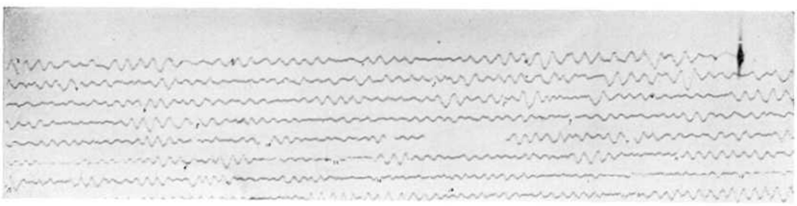
No. 16.



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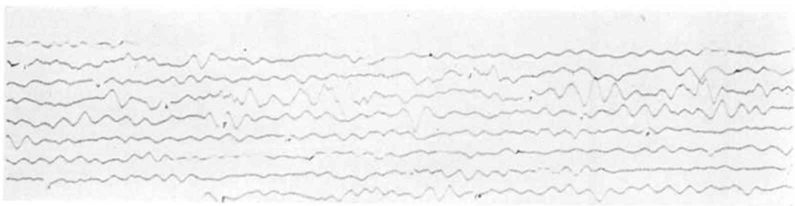

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No. 10. Irregular type

Fig. 5c. Ditto.

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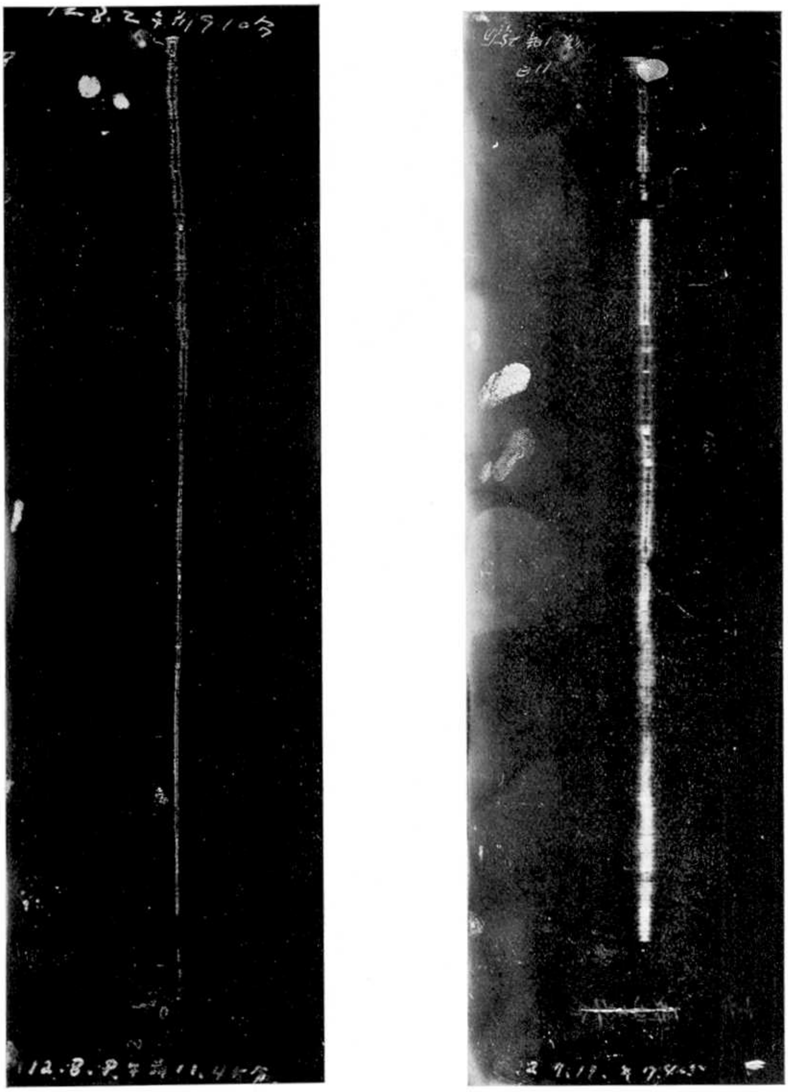

Fig. 15. Records obtained with the new seismograph which records direct on smoked paper the growth and decay of the tremors.

oscillations whose periods reach several seconds, which, since they were observed by K. Sassa at volcano Aso, we may expect also at Mihara when it is active. We may also expect surface waves of long period in the form of Love waves. As already stated, in order to increase our knowledge of the nature of the tremors to a further extent, measurements of the phase relations by rigidly controlled simultaneous observations are indispensable. We are now making preparations for solving these problems relating to the tremors in Oosima.

In conclusion, the writers wish to express their hearty thanks to the Hattori Hôkôkai, with the aid of whose grant the present measurements were made.

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8. 大島三原火山の地球物理學的研究 (第三報)

火山微動の測定

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倍率 2000 倍の逆立振子微動計を持ち廻つて，大島内に成る可く一樣になる樣に選定した十九の觀測點で微動の觀測を行つた，其の結果 2~3 の例外を除けば，微動は外輪山の內部では種々な周期から成る振動をしてゐるが，外輪山頂より外側では次第に單純な周期となり，海岸に行くと今度は不規則な振動が混る樣になる事が判つた．周期分析を行つた結果では 0·3 秒附近の周期の振動が湯場以外のどの觀測點にも現れる事が判つた．又各々の觀測點での微動の振幅を，西側外輪山の項上にある御神火茶屋に据付けてある 400 倍微動計を基準として調べて見ると，微動の振幅は中央火口丘から離れるに從つて小さくなつて居り，其の減り方から考へて見ると，微動は現在の火口底か或は其の直下 100 米以內の點から發生して居る周期 0·3 秒の衝撃に起されてゐる地表の二次的振動であると思はれる，

此の考に邪魔になる樣な，特に振幅の大きい點も特に小さい點もない．海岸での不規則な振動は多分海の波の爲に出來るものであらう．又中央火口丘での複雜な振動の原因，並に火口の方向の振幅が其れに直角な方向の振動よりも概して大きい事實は，中央火口丘の獨立の振動によるのであるか，又は火口底から出て來た波が途中で性質が變るのによるのか，只今の測つた結果だけでは判らない．

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