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Abstract

We investigate the variations and other properties of the micro-tremors at the Volcano Aso observed by the Wichert seismographs in the Volcanological Laboratory since 1950. In this paper, we treat the first kind and the second kind of the micro-tremors of the four kinds which have been classified by K. Sassa. He studied in decade of 1930 the phenomenon that the micro-tremors stop rapidly before eruptions and again increased after them. This time, we perceive the same phenomenon in the eruptions of Apr., 1953, Dec., 1957, and June, 1958. Next, we can perceive that the values of NS-component/EW-component of amplitudes of the second kind increase from 0 to 1 at the eruptions. It is found that this disposition occured also in the violent eruptions of 1933. Thus, on the assumption that the crack parallel to the row of the present craters, which has been infered from the mode of vibration at the eruption-earthquake by K. Sassa, vibrates after the eruption, being accompanied with the magmatic reservoir, we calculate the azimuthal distributions of amplitudes and indicate that the transversal component is the same order as the longitudinal component in the direction of the Volcanological Laboratory.

1. Introduction

The jets of lava and volcanic ashes and gas, the deformation of the earth's surface near the craters, the volcanic earthquake and micro-tremors, and the volcanic geomagnetic variations have been studied by many investigators. With respect to the Volcano Aso, many geophysical facts were revealed by K. Sassa in decade of 1930[1)2)]. Particularly, he studied in detail

the volcanic micro-tremors which appeared remarkably at the Volcano Aso, and pointed out that the volcanic eruption could be foretell by investigating the variations of the micro-tremors which came before the eruption. It is already revealed that not only the period but also the mode of oscillation distinguish the first kind of micro-tremors from the second and that from the detailed investigations during the comparatively silent time, the mode of the first kind is a Love wave type and that of the second kind is a Rayleigh wave type[1]. This time, we will further reveal these points by investigating the latest volcanic actions. In the following we describe only the results of the analysis of recordings of the first kind and the second kind of micro-tremors by Wichert horizontal and vertical component seismographs. For, although there appear the micro-tremors of the shorter period than that of the above waves and they are observed by S. Yoshikawa[3] near the craters, those which have the amplitudes of the same order as the first kind of micro-tremors at the origin damp so perfecily as to be unable to be observed at the Volcanological Laboratory, owing to the short period.

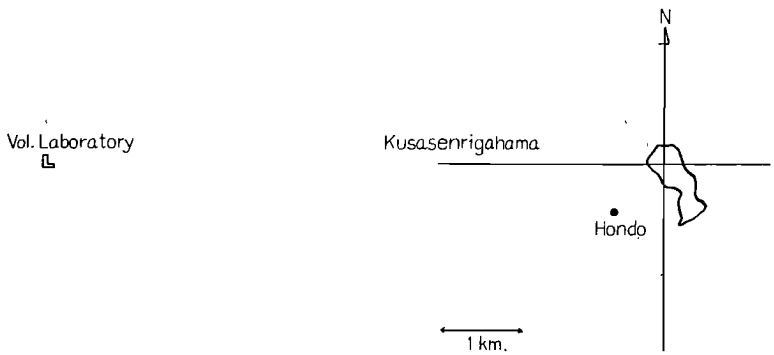

Fig. 1. Positions of Volcanological Laboratory and craters.

2. The micro-tremors and the eruptions between Apr. aud June of 1953.

The center of the eruption shifted from the fourth crater to the first and the second since Sep., 1932 and after the comparatively silent period between 1934~1950, we had a violent eruption of the first crater at 11^h32^m on Sep. 27th, 1953. Namely, after the small eruption on May, 1951, we had the silent time of two years and then the seismographs recorded the

regular waves of the first and the second kinds of the amplitudes of 0.5 μ and 1.5 μ since Apr. 14th and on 25th they interrupted rapidly and after calm state of three hours, we had a violent eruption of the first crater and abundant quantities of lava blocks of diameter of two feet were ejected, some of them being thrown 600 m. The amplitude of the first and the second kinds of micro-tremors which were recorded by Wichert seismographs at the Volcanological Laboratory during the active period, are shown in Fig. 2. The arrows indicate the eruption times when the lava blocks

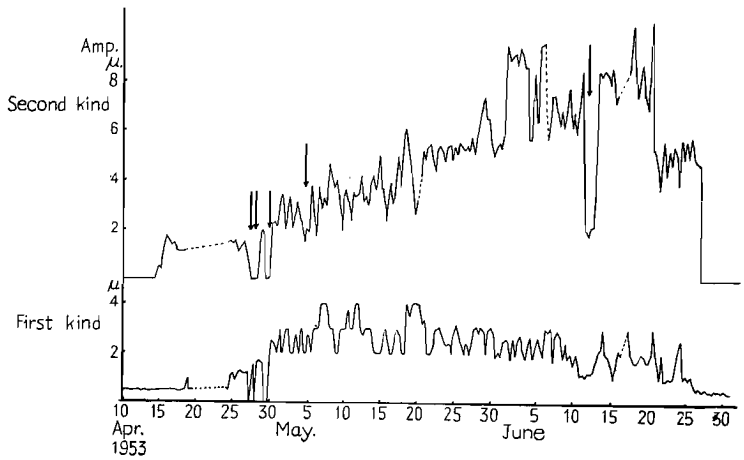

Fig. 2. Mean amplitude of micro-tremors.

were emitted. As known from this figure, the first crater exploded also at Apr. 28th, 29th and May 4th. The mean amplitude of the micro-tremors of the first kind which was 1 μ, and that of the second which was 1.5 μ increased 2.5 μ and 3~7 μ after the eruption, particularly, the second kind remarkably increased. Such a interruption of the micro-tremor just before the eruption is a character of that in April, and this fact gives the powerfull clue for the foretell. We see the same disposition also in decade of 1930.

3. The micro-tremors and the eruptions from July to Sep. of 1955.

The micro-tremors of the first kind which have been silent since July,

1953 increased on July 19th and the second increased on 24th. The second which had been the regular wave gradually became the continuous and irregular wave on July 25th and the amplitude increased to 3 μ, but, this time, the phenomenon that the micro-tremors interrupted just before the eruption was not clear and we could asertain only a irregularity in the wave form. Namely, we had the eruptions a few times on July 25th, particularly, the eruption at 10^h13^m was considerably strong, many lava blocks being ejected, and then the small eruptions were repeated on July 28th and 29th. The amplitudes of the first and second kinds of micro-tremors in this period are shown in Fig. 3.

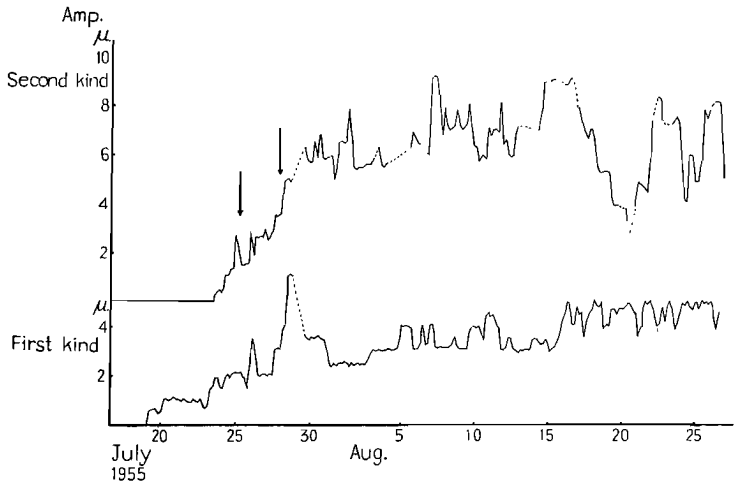

Fig. 3. Mean amplitude of micro-tremors.

Also, this time, the amplitudes after the eruption were larger than that before it. The micro-tremors of ca. 3 μ continued during Sep. and then damped gradually.

4. The micro-tremors and the euptions from Nov., 1957 to Jan., 1958.

After two years repose, on Nov. 17th, 1957, the micro-tremors of the first kind and the second kind began to increase gradually both in frequency of occurence and in amplitude. The first kind interrupted on Nov. 18th the second on Nov. 28th and the eruption occured at 19^h on Dec. 1st. The

micro-tremors for this time are shown in Fig. 4.

After this eruption, while the amplitude of the first kind was ca. 2 μ, the state of the second kind continued to rest, and the eruption occured at 1^h on Dec. 3rd, and then, the micro-tremors of the both kinds were slightly stronger than that before the eruption, continued in Dec. and damped gradually to April.

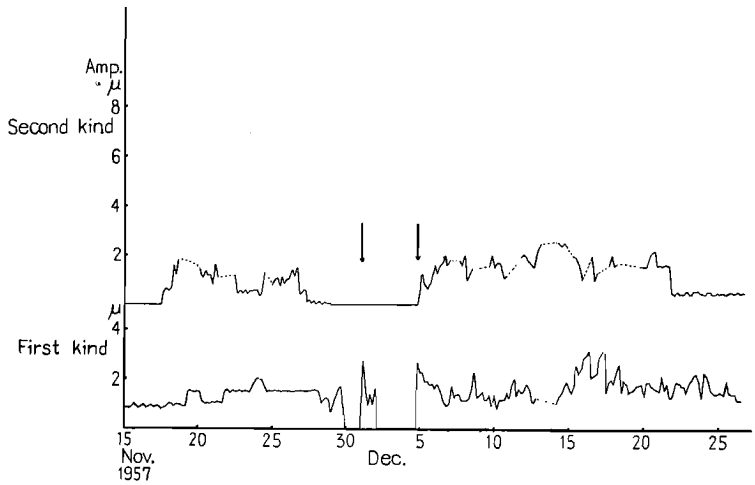

Fig. 4. Mean amplitude of micro-tremors.

5. The micro-tremors and the eruptions during June, 1958.

The smallness of the amplitudes of micro-tremors was a character of the eruption on June 24th, 1958, in comparison with the scale of the eruption, that is, the Wichert seismographs in the Volcanological Laboratory recorded only the micro-tremors of ca. 0.2~0.5 μ for a few days. However, the continuous micro-tremors of ca. 1 μ were recorded for some days before the eruption by the short period seismographs of very high magnifications in the Hondo's Observatory near the crater and interrupted two hours before the eruption and increased after it.

6. The characters of the variations of micro-tremors.

From the variation of the amplitudes of micro-tremors of the both kinds which occured between 1953~1958, we can summarize the following.

1) The micro-tremors of the both kinds occur several ten days before the eruption, the amplitudes larger than 1 μ at the Volcanological Laboratory continue and the micro-tremors which reach a maximum in amplitude and frequency of occurence often stop rapidly several hours or several days before the eruption. However, this disposition was not evident only in the eruption on July, 1957.

2) After the micro-tremors of the first kind of the amplitude of ca. 1 μ continue to be recorded within the limits of several days or several ten days, the state of them often return to rest without the eruption. For example, the end of June, 1954, the beginning of Jan., 1955, about the middle of Jan., 1957, and etc.. These are distinguished from the disposition of the micro-tremors before the eruption, by being accompanied with the second kind, and by the gradual stop of the first kind before it. However, to foretell the eruption, there are many points to study yet.

7. The variations of the mode of vibration of micro-tremor of the second kind

Irrespective of the activity of volcano, there occur the volcanic microtremors which have been called the second kind by K. Sassa, and the period of which is 3.5~8.0 sec.. The mode of oscillation was investigated by means of the simultaneous observations with the Galitzin type seismographs, which were set two points on Oct., 1932, and which were set six points on Aug., 1933.

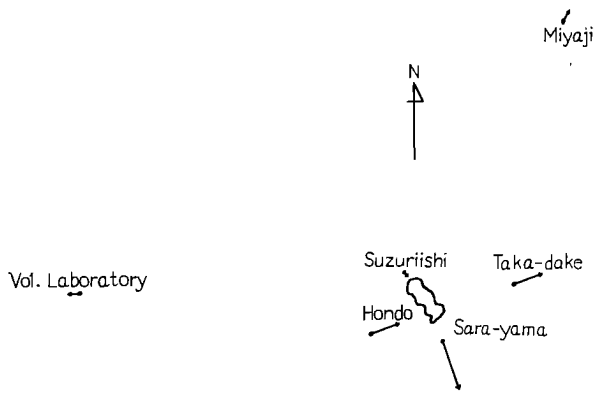

Fig. 5. Direction of horizontal displacements of micro-tremors of the second kind (after Sassa).

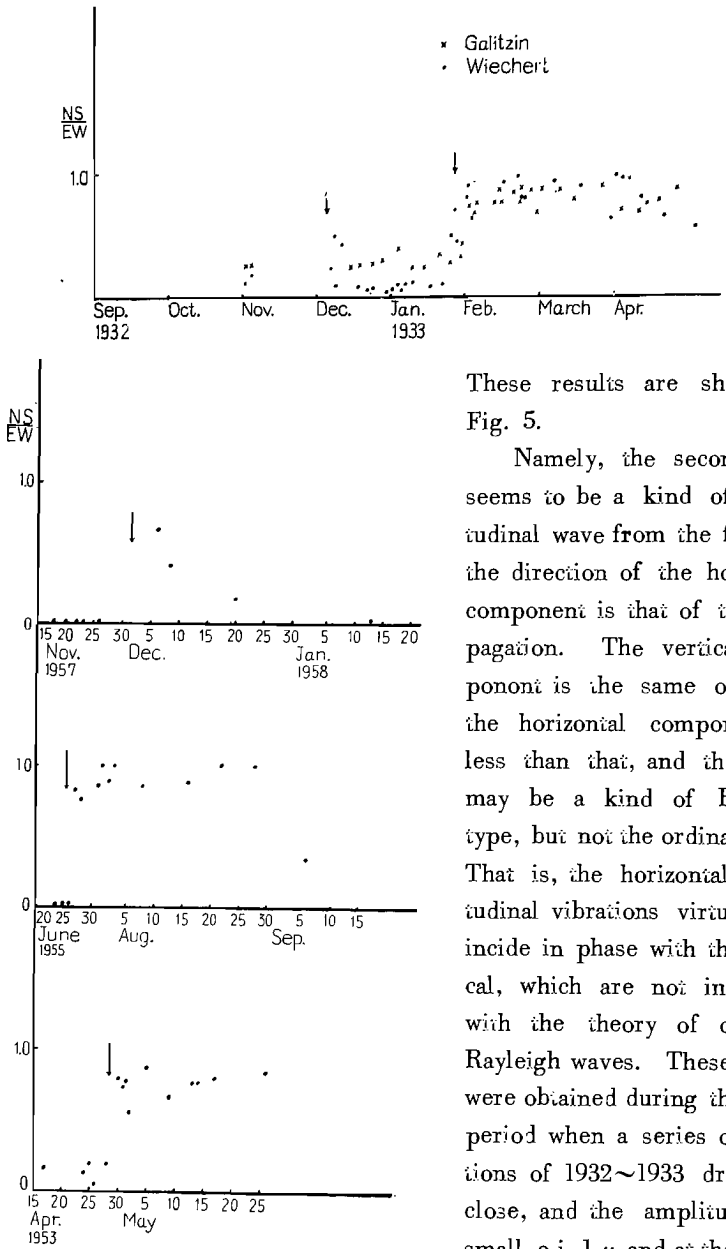

Fig. 6. Ratio of NS-component to EW-component of amplitude of micro-tremors of the second kind.

These results are shown in Fig. 5.

Namely, the second kind seems to be a kind of longitudinal wave from the fact that the direction of the horizontal component is that of the propagation. The vertical componont is the same order as the horizontal component or less than that, and then they may be a kind of Rayleigh type, but not the ordinary one. That is, the horizontal longitudinal vibrations virtually coincide in phase with the vertical, which are not in accord with the theory of ordinary Rayleigh waves. These results were obtained during the silent period when a series of eruptions of 1932~1933 drew to a close, and the amplitude was small, e.i. 1 μ and at the Volcanological Laboratory only the EW-component was recorded.

And also in the case of the eruption of Oct., 1932, they were about the same. These waves which occured towards the close of volcanic active period seem to be created from the magmatic reservoir of the considerable dimensions which is under the crater. We investigate the variations at eruption of the mode of vibration of the second kind of the period of ca. 3~4 sec., because the micro-tremors of the period larger than 5 sec. were not recorded. That is, the daily mean values of NS-component/EW-component of the second kind in Apr., 1953, July, 1955 and Dec., 1957 are read. The results are as follows.

The values increase from 0.2 to 0.8~0.9 at the volcanic eruptions.

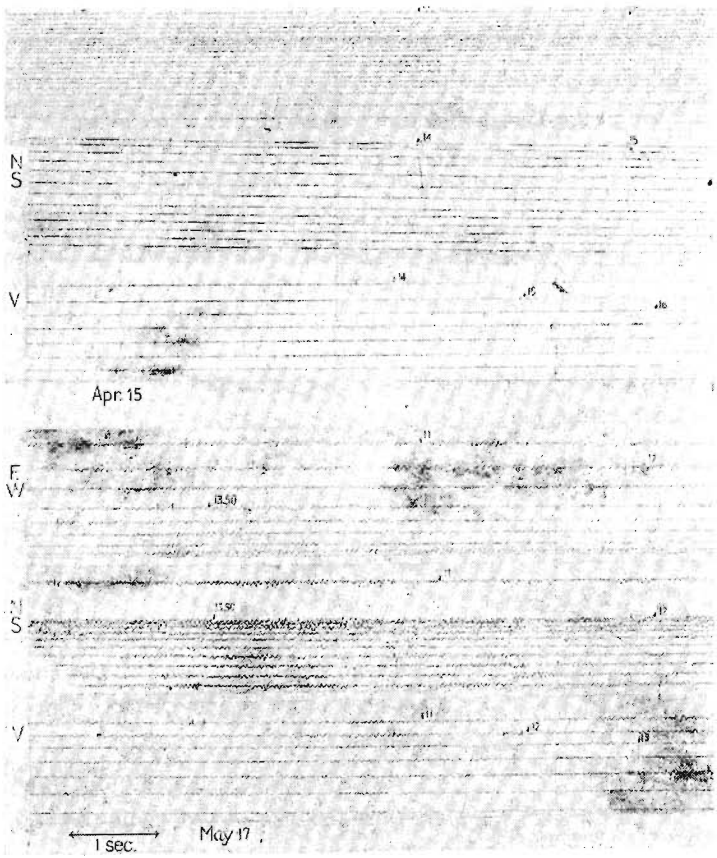

Fig. 7. Portions of records obtained from the Wicherts seismographs on Apr., 15, 1953 and May 17, 1953 at Vol. Lab.

Namely, the NS-component which do not occur yet before the eruption occurs after it. Also the mean values for the eruptions of 1933 are read, as shown in Fig. 6. As known in this figure it is evident that the same phenomena took place also in them. This fact suggests that a wave generates from the vibrational origin other than the magmatic reservoir, being accompanied with the vibration of it. Next, NS-component/V-component observed at the Volcanological Laboratory are plotted in Fig. 8. We obtain the result corresponding to the case of NS-component/EW-component. That is, while the vertical component of the same order as the EW-component both before and after the eruption, NS-component occur only after it.

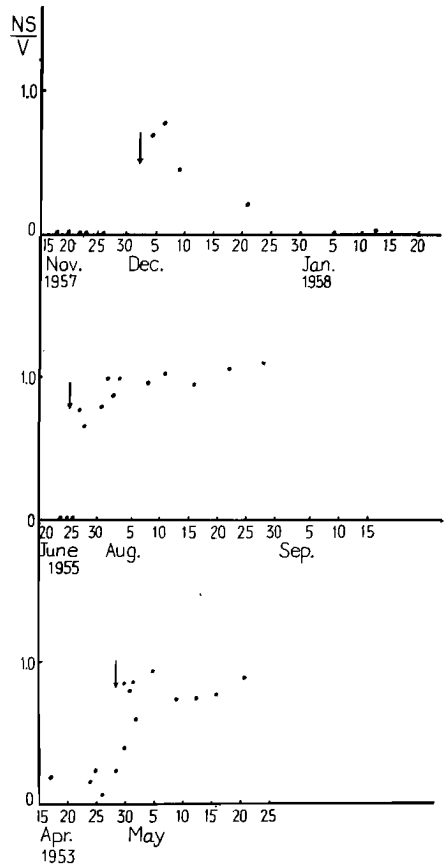

Fig. 8. Ratio of NS-component to V-component of amplitude of micro-tremors of the second kind.

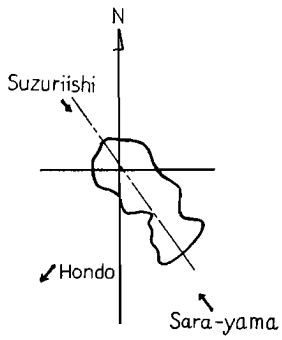

Fig. 9. Distribution of initial motions of eruption-earthquake of the First Crater in Aug. 1933 (after Sassa).

Previously, K. Sassa studied the mode of vibration near the crater of the small eruptive earthquake on July, 1933. The primary shocks are shown in Fig. 9.

It was indicated that the observed fact of the eruption earthquake could be fairly well explained by the vibration of crack parallel to the row of the present active craters.

After the considerable eruption, the ground will loosen near the reservoir and then the above vertical crack will become to be able to move perpendicular to the crack plane, being accompanied with the vibration of reservoir. Then the remarkable variations after the eruption of the mode of vibration of the second kind seem to be due to the waves generated from the above movements. In order that we examine if there occur the transversal component of the same order as that of the longitudinal component in the direction of the Volcanological Laboratory, we calculate the vibrational modes of the waves round the crater generated from the movements of crack of ca 1 km., which continues to the reservoir and is parallel to the row of craters.

8. The distributions of amplitude.

There lie the above crack of finite dimension, a certain depth under the surface, however, the complete treatment of such a problem would be so difficult to solve that we neglect the effect of the free surface and assume for simplicity that the length of the vertical direction is infinite, that is, the problem is reduced to two dimensional one. As we calculate the horizontal propagation of wave in the above problem, it seem to be valid. Using the elliptic coordinate, the wave equations are written as follows

$$\left.\begin{aligned} \rho\frac{\partial^2\Delta}{\partial t^2} &= \frac{\lambda+2\mu}{c^2(\cosh^2\xi-\cos^2\eta)}\left(\frac{\partial^2\Delta}{\partial\xi^2}+\frac{\partial^2\Delta}{\partial\eta^2}\right) \\ \rho\frac{\partial^2\omega}{\partial t^2} &= \frac{\mu}{c^2(\cosh^2\xi-\cos^2\eta)}\left(\frac{\partial^2\omega}{\partial\xi^2}+\frac{\partial^2\omega}{\partial\eta^2}\right) \end{aligned}\right\} \quad \cdots\cdots\cdots\cdots\cdots\cdots (1)$$

$$x = c\cosh\xi\cdot\cos\eta$$

$$y = c\sinh\xi\cdot\sin\eta$$

$$\Delta = h_1^2\left\{\frac{\partial}{\partial\xi}\left(\frac{u}{h_1}\right)+\frac{\partial}{\partial\eta}\left(\frac{v}{h_1}\right)\right\}$$

$$2\omega = h_1^2\left\{\frac{\partial}{\partial\xi}\left(\frac{v}{h_1}\right)+\frac{\partial}{\partial\eta}\left(\frac{u}{h_1}\right)\right\}$$

$$\frac{1}{h_1^2} = c^2(\cosh^2\xi-\cos^2\eta),$$

where

u, v = components of displacement refered to curvilinear coordinates,

ρ = density of isotropic solid,

λ, μ = Lames elastic constants.

According to K. Sezawa,[6)7)] the solutions of these equations are expressed as follows

$$\left.\begin{aligned} \Delta &= \sum_{n=0}^{\infty} B_n H_n(\xi, q) G_n(\eta, q) e^{ipt} \\ 2\omega &= \sum_{n=0}^{\infty} C_n H_n(\xi, q') G_n(\eta, q') e^{ipt}, \end{aligned}\right\} \quad \cdots\cdots\cdots\cdots\cdots\cdots (2)$$

where

$$q = \frac{h^2c^2}{32}, \quad q' = \frac{k^2c^2}{32}, \quad \frac{\rho p^2}{\lambda+2\mu} = h^2, \quad \frac{\rho p^2}{\mu} = k^2.$$

$G_n(\eta, q)$, $G_n(\eta, q')$ are Mathiues functions and $H_n(\xi, q)$, $H_n(\xi, q')$ are the solutions of the following equations

$$\left.\begin{aligned} &\frac{d^2H_n(\xi, q)}{d\xi^2} + (h^2c^2 \cosh^2 \xi - n^2) H_n(\xi, q) = 0 \\ &\frac{d^2H_n(\xi, q')}{d\xi^2} + (k^2c^2 \cosh^2 \xi - n^2) H_n(\xi, q') = 0. \end{aligned}\right\} \cdots\cdots\cdots\cdots\cdots (3)$$

u_1, v_1 the components of displacements of the dilational wave and v_2, v_2 those of the distortional wave are given by

$$\left.\begin{aligned} u_1 &= -\sum_{n=0}^{\infty} \frac{h_1 B_n}{h^2} \frac{\partial H_n}{\partial \xi} (\xi, q) G_n(\eta, q) e^{ipt} \\ v_1 &= -\sum_{n=1}^{\infty} \frac{h_1 B_n}{h^2} H_n(\xi, q) \frac{\partial G_n}{\partial \eta} (\eta, q) e^{ipt} \\ u_2 &= -\sum_{n=1}^{\infty} \frac{h_1 C_n}{k^2} H_n(\xi, q') \frac{\partial G_n}{\partial \eta} (\eta, q') e^{ipt} \\ v_2 &= -\sum_{n=1}^{\infty} \frac{h_1 C_n}{k^2} \frac{\partial H_n}{\partial \xi} (\xi, q') G_n(\eta, q') e^{ipt}. \end{aligned}\right\} \cdots\cdots\cdots\cdots\cdots (4)$$

In this case, as the gas rich magma seem to press only vertically the surface of crack, the boundary conditions are given by

$$\left.\begin{aligned} &\text{normal stress} = \left[\lambda\Delta + 2\mu\left\{h_1 \frac{\partial(u_1+u_2)}{\partial \xi} + h_1^2(v_1+v_2)\frac{\partial(1/h_1)}{\partial \eta}\right\}\right]_{\xi_0=0} = Se^{ipt} \\ &\text{tangential stress} = \mu\left[\frac{\partial h_1(v_1+v_2)}{\partial \xi} + \frac{\partial h_1(u_1+u_2)}{\partial \eta}\right]_{\xi_0=0} = 0. \end{aligned}\right\} \cdots (5)$$

When ξ approaches 0, asymptotic relations are known such as

$$H_n(\xi, q) \to 1 \qquad \frac{\partial H_n(\xi, q)}{\partial \xi} \to -i\sqrt{h^2c^2 - n^2}$$

$$H_n(\xi, q') \to 1 \qquad \frac{\partial H_n(\xi, q')}{\partial \xi} \to -i\sqrt{k^2c^2 - n^2}.$$

Taking the physical conditions into consideration, Mathieu function for the dilatational component is even with respect to η, while that for the distortional component is odd. Then, the boundary conditions (5) are reduced into the following expressions

$$\left.\begin{aligned}
S=\mu\Big[&\sum_{n=0}^{\infty} B_n G_n(\eta, q)+\frac{1}{\sin^2\eta}\Big\{-\sum_{n=0}^{\infty} \alpha_n B_n G_n(\eta, q)+\sum_{n=1}^{\infty} \beta_n C_n \frac{\partial G_n(\eta, q')}{\partial \eta}\Big\} \\
&-\frac{\cos\eta}{\sin^3\eta}\Big\{\sum_{n=1}^{\infty} \gamma B_n \frac{\partial G_n(\eta, q)}{\partial \eta}+\sum_{n=1}^{\infty} \beta_n C_n G_n(\eta, q')\Big\}\Big] \\
0=\mu\Big(&-\frac{\alpha_0' B_0}{\sin^2\eta}\frac{\partial G_0(\eta, q)}{\partial \eta}-2\sum_{n=1}^{\infty}\frac{\alpha_n' B_n}{\sin^2\eta}\frac{\partial G_n(\eta, q)}{\partial \eta}+\sum_{n=0}^{\infty}\frac{\alpha_n' B_n \sin 2\eta}{\sin^4\eta} G_n(\eta, q) \\
&-\sum_{n=1}^{\infty}\frac{\beta_n' C_n}{\sin^2\eta} G_n(\eta, q')+\sum_{n=1}^{\infty}\Big\{-\frac{\gamma' C_n \sin 2\eta}{\sin^4\eta}\frac{\partial G_n(\eta, q')}{\partial \eta}+\frac{\gamma' C_n}{\sin^2\eta}\frac{\partial^2 G_n(\eta, q')}{\partial \eta^2}\Big\}\Big)
\end{aligned}\right\} \quad \cdots\cdots(6)$$

where

$$\alpha_n=2\Big(\frac{n^2}{h^2c^2}-1\Big), \quad \beta_n=\frac{-2i\sqrt{k^2c^2-n^2}}{k^2c^2}, \quad \gamma=\frac{2}{h^2c^2},$$

$$\alpha_n'=\frac{-i\sqrt{h^2c^2-n^2}}{h^2c^2}, \quad \beta_n'=\frac{n^2-k^2c^2}{k^2c^2}, \quad \gamma'=\frac{1}{k^2c^2}.$$

In order to solve the problem approximatelly, we use Mathieu functions of 0th to 6th orders, and neglect the higher terms in q. The Mathieu functions are given by

$$\left.\begin{aligned}
&ce_0=1+4q\cos 2\eta, && ce_1=\cos\eta+q\cos 3\eta, \\
&ce_2=\cos 2\eta+q\Big(\frac{2}{3}\cos 4\eta-2\Big), && ce_3=\cos 3\eta+q\Big(-\cos\eta+\frac{1}{2}\cos 5\eta\Big), \\
&ce_4=\cos 4\eta+q\Big(-\frac{2}{3}\cos 2\eta+\frac{2}{5}\cos 6\eta\Big), && \\
&se_1=\sin\eta+q\sin 3\eta, && se_2=\sin 2\eta+\frac{2}{3}q\sin 4\eta, \\
&se_3=\sin 3\eta+q\Big(-\sin\eta+\frac{1}{2}\sin 5\eta\Big), && se_4=\sin 4\eta+q\Big(-\frac{2}{3}\sin 4\eta+\frac{2}{5}\sin 6\eta\Big).
\end{aligned}\right\} \quad \cdots\cdots(7)$$

Using these functions, the normal stress and the tangential stress at the crack plane are expressed by

$$\begin{aligned}
&S_0+\sum_{n=1}^{\infty} S_n\cos n\eta \\
&\quad=\mu\Big[S_{11}B_0+S_{12}B_2+S_{13}B_4+S_{14}C_2+S_{15}C_4+\cdots\cdots
\end{aligned}$$

$$
\left.
\begin{aligned}
&+(S_{21}B_0+S_{22}B_2+S_{23}B_4+S_{24}C_2+S_{25}C_4+\cdots\cdots)\frac{1}{\sin^2\eta}\\
&+(S_{31}B_0+S_{32}B_2+S_{33}B_4+S_{34}C_2+S_{35}C_4+\cdots\cdots)\cos 2\eta\\
&+(S_{41}B_0+S_{42}B_2+S_{43}B_4+S_{44}C_2+S_{45}C_4+\cdots\cdots)\cos 4\eta\\
&+\cdots\cdots\Big]\\
&\sum_{n=1}^{\infty}S_n'\sin n\eta\\
&=\mu\Big[(S_{11}'B_0+S_{12}'B_2+S_{13}'B_4+S_{14}'C_2+S_{15}'C_4+\cdots\cdots)\frac{\cos\eta}{\sin^3\eta}\\
&+(S_{21}'B_0+S_{22}'B_2+S_{23}'B_4+S_{24}'C_2+S_{25}'C_4+\cdots\cdots)\sin 2\eta\\
&+\cdots\cdots\Big],
\end{aligned}
\right\}\cdots\cdots(8)
$$

where

$$
\left.
\begin{aligned}
&S_{11}=1+8q\alpha_0\\
&S_{12}=-2q+2\alpha_2+\frac{8}{3}q\alpha_2-4\gamma-\frac{64}{3}q\gamma\\
&S_{13}=\frac{16}{15}q\alpha_4+4\alpha_4-32\gamma-\frac{608}{15}q\gamma\\
&S_{14}=-2\beta_2-\frac{16}{3}q'\beta_2\\
&S_{15}=-8\beta_4-\frac{88}{15}q'\beta_4\\
&S_{21}=-\alpha_0-4q\alpha_0\\
&S_{22}=-\alpha_2+\frac{4}{3}q\alpha_2+4\gamma+\frac{32}{3}q\gamma\\
&S_{23}=-\alpha_4+16\gamma+\frac{4}{15}q\alpha_4+\frac{176}{15}q\gamma\\
&S_{24}=0\\
&S_{25}=0\\
&S_{31}=4q\\
&S_{32}=1+\frac{8}{3}q\alpha_2-\frac{32}{3}q\gamma\\
&S_{33}=-\frac{2}{3}q+4\alpha_4+\frac{16}{5}q\alpha_4-16\gamma-\frac{192}{5}q\gamma\\
&S_{34}=-8q'\beta_2\\
&S_{35}=-12\beta_4-\frac{64}{5}q'\beta_4\\
&S_{41}=0
\end{aligned}
\right\}\cdots\cdots\cdots\cdots\cdots\cdots(9)
$$

$$
\left.
\begin{aligned}
&S_{42}=\frac{2}{3}\,q\\
&S_{43}=1+\frac{8}{5}\,q\alpha_4-\frac{48}{5}\,q\gamma\\
&S_{44}=0\\
&S_{45}=-8q'\beta_4\\
&S_{11}'=2\alpha_0'+8q\alpha_0'\\
&S_{12}'=2\alpha_2'-\frac{8}{3}\,q\alpha_2'\\
&S_{13}'=2\alpha_4'-\frac{8}{15}\,q\alpha_4'\\
&S_{14}'=-4\gamma'-\frac{16}{3}\,q'\gamma'\\
&S_{15}'=-8\gamma'-\frac{32}{15}\,q'\gamma'
\end{aligned}
\right|
$$

Now we consider the case that uniform pressure changes periodically with time, and the tangential stress is zero. Moreover, we may put for symmetry,

$$B_1\equiv B_3\equiv C_1\equiv C_3\equiv 0.$$

Then, we obtain the following simultanious equations

$$
\left.
\begin{aligned}
&S_{11}B_0+S_{12}B_2+S_{13}B_4+S_{14}C_2+S_{15}C_4=S_0/\mu\\
&S_{21}B_0+S_{22}B_2+S_{23}B_4+S_{24}C_2+S_{25}C_4=0\\
&S_{31}B_0+S_{32}B_2+S_{33}B_4+S_{34}C_2+S_{35}C_4=0\\
&S_{41}B_0+S_{42}B_2+S_{43}B_4+S_{44}C_2+S_{45}C_4=0\\
&S_{11}'B_0+S_{12}'B_2+S_{13}'B_4+S_{14}'C_2+S_{15}'C_4=0.
\end{aligned}
\right\}\quad\cdots\cdots\cdots\cdots\cdots(10)
$$

We obtain B_0, B_2, B_4, C_2, C_4 from these equations.

When ξ is large, the asymptotic expressions for $H_n(\xi, q)$, $H_n(\xi, q')$ are obtained in the following form.

$$
\left.
\begin{aligned}
&H_n(\xi, q)\rightarrow\frac{e^{-ihc\sinh\xi}}{\sqrt{hc\sinh\xi}}\\
&H_n(\xi, q')\rightarrow\frac{e^{-ikc\sinh\xi}}{\sqrt{kc\sinh\xi}}.
\end{aligned}
\right\}\quad\cdots\cdots\cdots\cdots\cdots\cdots(11)
$$

Thus, the radial component of the dilational wave u_1 and the tangential component of the distortional wave v_2 at a distant are given on insertion of (11) into (4) by

$$
\left.
\begin{aligned}
u_1 &= -\sum_{n=0}^{\infty} \frac{B_n}{h^2 c\sqrt{\cosh^2\xi-\cos^2\eta}} \frac{\partial H_n(\xi, q)}{\partial \xi} ce_n(\eta, q) e^{ipt} \\
&= -\sum_{n=0}^{\infty} \frac{1}{h^{3/2}R^{1/2}} \left\{ a_n ce_n(\eta, q)\sin(pt-hR) + b_n ce_n(\eta, q)\cos(pt-hR) \right\} \\
v_2 &= -\sum_{n=1}^{\infty} \frac{C_n}{k^2 c\sqrt{\cosh^2\xi-\cos^2\eta}} \frac{\partial H_n(\xi, q')}{\partial \xi} se_n(\eta, q') e^{ipt} \\
&= -\sum_{n=1}^{\infty} \frac{1}{k^{3/2}R^{1/2}} \left\{ c_n se_n(\eta, q')\sin(pt-kR) + d_n se_n(\eta, q')\cos(pt-kR) \right\},
\end{aligned}
\right\}
\quad \cdots\cdots\cdots\cdots\cdots\cdots (12)
$$

where

$$B_n = a_n + ib_n, \quad C_n = c_n + id_n$$

$$R = \text{the distance from the origin.}$$

New we put

$$T = 4\,\text{sec.}$$

$$2c/v_s = 1.32,$$

where $2c$ = length of crack.

On results of calculations of a_n, b_n, c_n, d_n, we obtain

$$
\left.
\begin{array}{lll}
a_0 = 0.02346, & a_2 = -0.01584, & a_4 = -0.001562, \\
b_0 = -0.09339, & b_n = 0.08791, & b_4 = 0.0008799, \\
d_2 = 0.1214, & d_4 = 0.001355, & \\
c_2 = -0.1645, & c_4 = -0.001651. &
\end{array}
\right\}
\quad \cdots\cdots\cdots (13)
$$

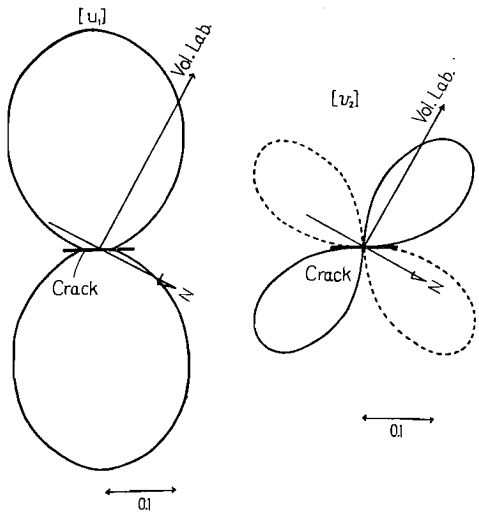

Fig. 10. Azimuthal distributions of displacements, u_1 and v_2, at a distant point.

The azimuthal distribution of u_1, v_2 in this case is shown in Fig. 10.

We thought previously that the gas riched magma in the reservoir which was infered to exist under the craters frequently exploded in the active period of the Volcano Aso and being accompanied with it, there occured the micro-tremors of the second kind, and then indicated that the dimensions of the reservoir

corresponding to the period of the second kind is the order of 1 km, on the assumption that the form of the reservoir is a sphere[4)5)]. As a result of the above investigation, we find that a transversal wave propagates simultaneously with a longitudinal wave during the short period after the considerable eruption. The above calculations indicate that when there exist the crack of the order of 1 km which connect with the reservoir and after the eruption it operates as the origin of waves with reservoir, the transversal wave of the same order as the longitudinal wave propagates in the direction of the Volcanological Laboratory. Therefore, it is infered from the appearance of the transversal component only during the short period after the eruption that there occur the rapid changes in the ground around the reservoir and in the distribution of the gas riched magma and that they restore to the state before the eruption with the decrease of the volcanic activity. As we did not observe at many points for the long period, we cannot bring the unambiguous conclusions, however, the above mechanism of the wave generation near the crater can explains the observed results.

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