GEOPHYSICAL STUDIES AT SAKURAJIMA VOLCANO

BY

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1. Aspect of volcano activity

Since the eruption of Oct., 13 th, 1955, the center of the activity of the Sakurajima is the old crater of Minamidake in where a eruption has been not occured in history, and in fact there have been about over a thousand eruptions since then. These eruption are characterized by Volcano type, with eruption cloud rising up often to the height of thousands meters and lava fragments sometimes thrown away about over 2 km from the crater.

In order to estimate the discharged energy by eruption in this active period. the successive sums of the squares of maximum amplitude of eruption earthquakes are shown in Fig. 1. It is found that the discharged energy was acceleratively increased with time, especially in 1960.

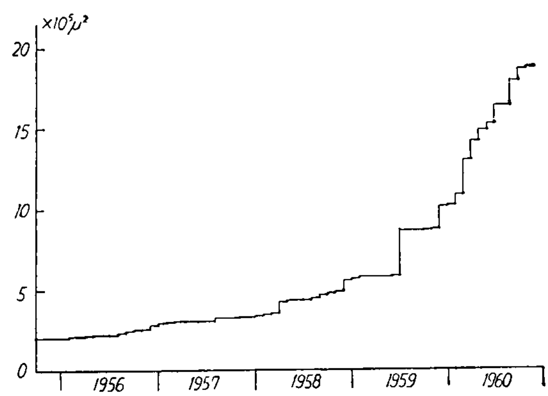

Fig. 1 Successive accumulation of the square of maximum amplitude of eruption earthquake.

2. Precise levelling

Four successive precise levellings along the route around this volcano (Fig. 2) were carried out once every year. Vertical displacements in each period are shown in Fig. 3. It may be considered that these vertical displacements shall be occured

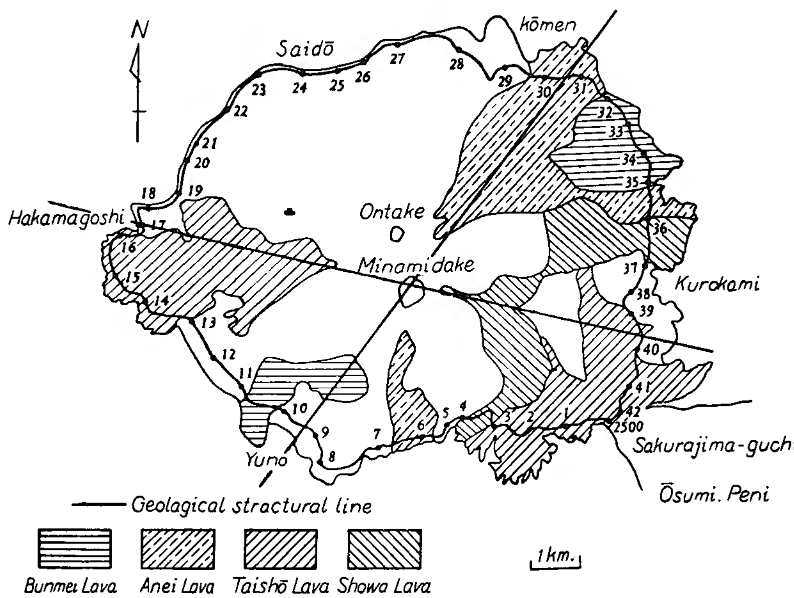

Fig. 2 The position of benchmarks and the distribution of the lava-flow in histry in Sakurajima.

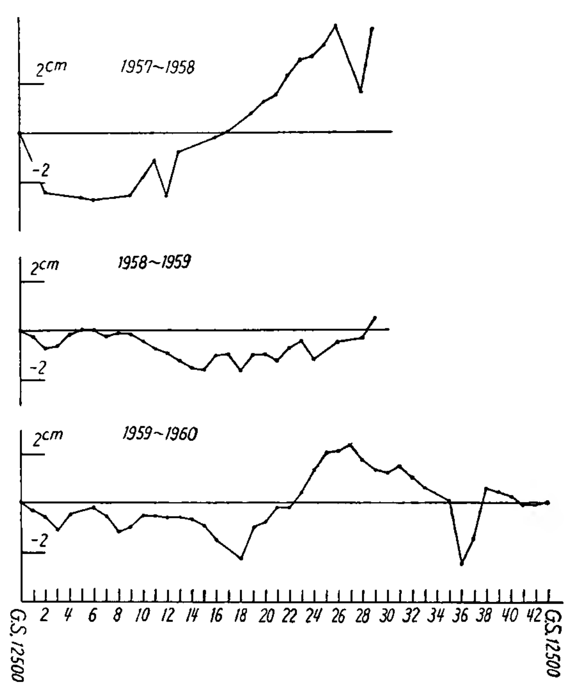

Fig. 3 The vertical displacement of benchmarks in the respective periods.

by the movement of pressure center in the vicinity beneath the volcano and the change of the pressure.

According to the theory of elasticity, the deformation of the semi-infinite elastic body caused by the change of hydrostatic pressure in small sphere in it, is calculated as follows.

$$U_Z=\frac{a^3P}{4\mu}\frac{1}{\{(Z+2f)^2+R^2\}^{5/2}}\cdot(7Z^3+38fZ^2+68f^2Z+40f^3+4fR^2+ZR^2)$$
$$+\frac{a^3P}{4\mu}\left[\frac{Z}{(Z^2+R^2)^{3/2}}+\frac{Z+2f}{\{(Z+2f)^2+\mathrm{R}^2\}^{3/2}}\right]$$

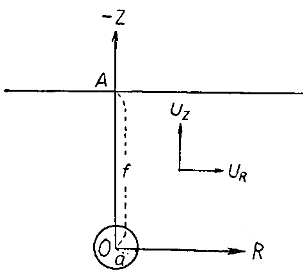

Fig. 4

where U_Z: displacement in the direction vertical to surface,
a: radius of the small sphere where the hydorostatic pressure taken place,
P: change of the hydrostatic pressure in small sphere,
f: depth from the surface to the center of the sphere,
and μ: Lame's constant.

Now, substituting Z by $-f$ in the above equation, the vertical displacement at any point on the ground surface is described as

$$\Delta h=\frac{3a^3P}{4\mu}\frac{f}{(f^2+d^2)^{3/2}}$$

in which $d(\equiv R)$: distance from the point A to a point on the ground surface,
Δh: vertical displacement on the ground surface.

Comparing the measured displacement with calculated one from the above equation, we can determine the position of pressure center and the variation of a^3P/μ. As a consequence, the main pressure center seems to be situated at the depth of 10 km beneath the center of Aira caldera, at the southern rim of which Sakurajima is situated, and the sub-pressure center at the depth of 3 km beneath Kitadake the summit of which is highest in Sakurajima. And then each value of a^3P/μ during each period is varied as follows:

$(a^3P/\mu)_{1957-58}=1$
$(a^3P/\mu)_{1957-59}=1.06$ in main pressure center,
$(a^3P/\mu)_{1959-60}=0.70$
and $(a^3P/\mu)_{1959-60}=0.07$ in sub-pressure center,
where the value of 1957-58 is taken 1 as an unit.

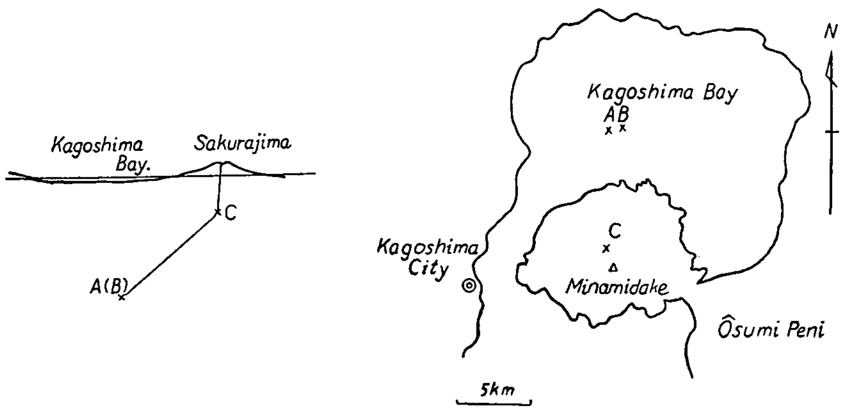

Fig. 5 The positicn of the pressure center.
A : 1957-58, B : 1958-59 and 1959-60, C : 1959-60.

The position of the main pressure center is neary as same as that estimated by Mogi who treated the results of successive levelling along the cost of Kagoshima Bay before and after the eruption of this volcano in 1914. And it is very interesting that the value of a^3P/μ in main pressure center increased with time, especially rapidly increased in 1959-60, when the discharged energy by the eruption as described in chap. 1 was remarkable.

3. Tide gauge observation

Since July, 1958, the observation of the change of sea level by Roll type tide gauge has been carried out at Hakamagoshi in Sakurajima. Fortunately, it has been made also as routine work of Kagoshima Meteological Observatory at Kagoshima Harbor which is apart about 4 km westwards from Hakamagoshi.

The monthly mean values of the sea levels at both stations and differences of these values are shown in Fig. 6. It is found that during the last two years the

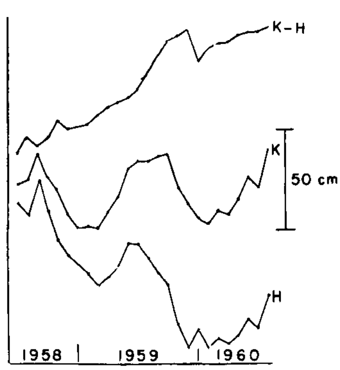

Fig. 6 The change of the monthly mean values of the sea-level, and the change of the differences of these values between two stations.
H : Hakamagoshi. K : Kagoshima.

ground of Hakamagoshi upheaved about 60 cm respective to Kagoshima. But we can not explaine the relative movement between both stations by the described pressure center model in chap. 2. Therefore we must explaine the model to alter the position of pressure center. For a example let us consider the case of 1959–60. Let the value of $3a^3P/4\mu$ be a function of the depth of main pressure center under the condition that the relative vertical displacement of benchmarks of Sakurajima is as satisfied as possible, then the values of uplifts of Hakamagoshi and Kagoshima are tabled as follows.

depth	$3a^3P/4\mu$	uplift of Hakamagoshi	uplift of Kagoshima
km	$\times 10^{18}\text{cm}^3$	cm	cm
5	0.18	0.5	0.3
10	0.57	1.7	1.2
15	1.66	3.9	3.1
20	4.00	6.7	5.9
25	7.04	8.6	7.8
30	12.5	11.5	10.6
40	34.5	19.4	18.5
45	57.8	26.2	25.3
50	90.9	33.7	32.8

On examining the table, we can consider as follows:

1) When the change of sea level (26.3 cm) at Hakamagoshi in the period from Mar. 1959 to Mar. 1960 (the precise levelling had been carried out in Mar. of each year) would be regarded as uplift of the ground, the depth of main pressure center must be about 45 km in order to reconcil the model with the uplift of Hakamagoshi. And in the case of the depth less than 45 km we must consider another force uplifting Sakurajima.

2) There is no case where both uplifts of Hakamagoshi and Kagoshima are simultenously reconciled. That is, a vertically discontinuous movement as fault-slip between them must be taken into consideration.

4. Prediction of volcanic eruption by tiltmeter and extensometer

To observe continuously the crustal deformation in the vicinity of the volcano, horizontal pendulum tiltmeters, Sassa type extensometers (horizontal) and bar type extensometer (vertical) are set up in two tunnels. One is situated at Hakamagoshi being 5.6 km apart in WNW from the crater, and the other at Hiyamizu being 11 km apart in WNW from it.

The characteristic crustal deformation was many often recorded by these instruments before the eruption. Examining the behaviour of crustal deformation before eruption, we can point out its particular form different from usual form recorded where no eruption takes place (denoted by abnomal deformation in the following).

On 29 th Mar., 1960, the hot lava flowed out on the old crater bottom of Minamidake, and its mass amounted to 600,000 tons, the largest in this period. And the volcanic micro-tremors occurred continuously with large amplitude, which may be comparable with that of eruption in 1946 when a great deal of lava flowed out from the eastern frank of Minamidake.

The crustal deformation recorded by each instrumant on this occassion is shown Fig. 7. In these figures, full line is the original record that the *abnormal deformation* associated with the eruption supperpose on the sinusoidal deformation caused by the oceanic tide, and broken line is the overlapping mean of thirteen successive values at an interval of 2 hours from the original record and shows

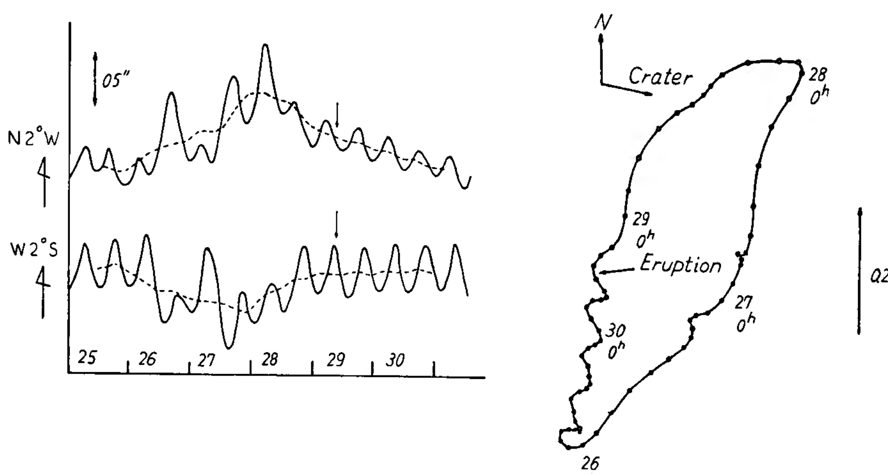

Fig. 7 (a) Abnormal tilt at Hakamagoshi on the occasion of the eruption on 29 th of Mar., 1960.

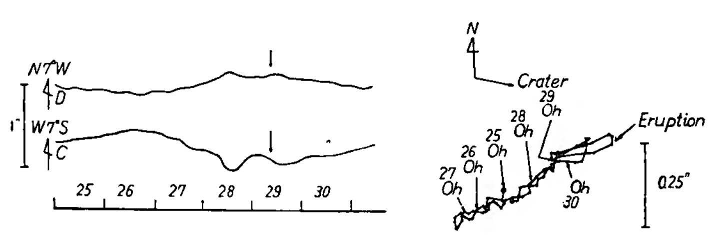

Fig. 7 (b) Abnormal tilt at Hiyamizu on the occasion of the eruption on 29 th of Mar., 1961.

the *abnormal deformation.*

As seen from them, the tiltmeters at two stations recorded the abnormal tilt, and also the extensometer of vertical at Hakamagoshi recorded the abnormal contraction at same time although that in horizontal did not so clearly.

In the case of the eruption on 24 th Feb., 1959, which was not so great eruption, the tiltmeter at Hakamagoshi also recorded the abnormal tilt as shown in Fig. 8, but

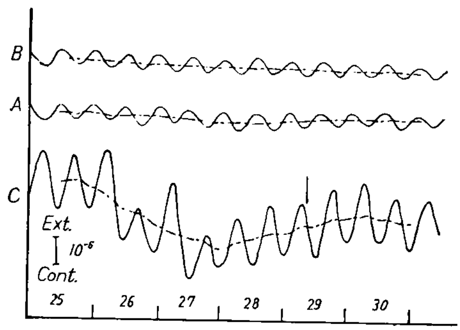

Fig. 7 (c) Abnormal vertical contraction at Hakamagoshi on the occasion of the eruption on 29 th of Mar., 1960.

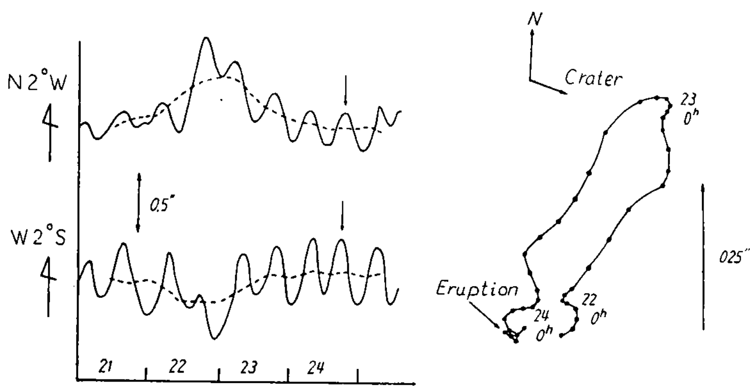

Fig. 8 Abnormal tilt at Hakamagoshi on the occasion of the eruption on 24 th of Feb., 1959.

another instrumants did not.

From these example, it is found that the tiltmeter at Hakamagoshi begin to record the abnormla tilt downwards NE direction several days before an eruption and the eruption takes place on the way of returning to original position of after its return to original position. The extensometer of vertical component records the abnormal contraction corresponding to the abnormal tilt. When a lot of hot lava uplifted, the tiltmeter at Hiyamizu also records an abnormal tilt downwards NE direction several days before the eruption. These characteristic deformation may give a clue for the prediction of eruption of this volcano, although the direction of tilt does not always show the uplift of the crater.