DISASTER PREVENTION RESEARCH INSTITUTE
BULLETIN No. 48 AUGUST, 1961

ON THE CRUSTAL MOVEMENT ACCOMPANYING WITH THE RECENT ACTIVITY OF THE VOLCANO SAKURAJIMA (PART 1)

BY

KEIZO YOSHIKAWA

KYOTO UNIVERSITY, KYOTO, JAPAN

Errata

p. 2, line 8, for "from" read "form".

p. 2, line 26, for "leva-streams" read "lava-streams".

p. 3, line 8, for "Pecies" read "Precise".

p. 4, line 6, for "precised" read "precise".

p. 6, line 9, for "improtance" read "importance".

p. 7, line 15, for "$\frac{a^3P}{4\mu}\left(\frac{1}{(Z^2+R^2)^{3/2}}+\frac{R}{\{(Z+2f)^2+R^2\}^{3/3}}\right)$" read

$$\frac{a^3P}{4\mu}\left[\frac{R}{(Z^2+R^2)^{3/2}}+\frac{R}{\{(Z+2f)^2+R^2\}^{3/2}}\right],$$

p. 8, line 13, for "assume" read "assumed".

p. 8, line 15, for "as possible" read "as be possible".

p. 11, line 16, for "influened" read "influenced".

p. 13, line 7, for "showm" read "shown".

p. 13, line 23, for "magman" read "magma".

p. 14, line 23, for "effered" read "offered".

p. 14, line 30, for "Use-San" read "Usu-San".

DISASTER PREVENTION RESEARCH INSTITUTE
KYOTO UNIVERSITY
BULLETINS

Bulletin No. 48 August, 1961

On the Crustal Movement Accompanying with the Recent Activity of the Volcano Sakurajima (part 1)

By

Keizo YOSHIKAWA

On the Crustal Movement Accompanying with the Recent Activity of the Volcano Sakurajima (part 1)

By

Keizo YOSHIKAWA

1. Introduction

It is well known that with great volcanic eruptions enormous volume of magma moves up to the earth's surface in a from of lava-flow or fragmental ejecta from magma reservoir. Owing to this movement, it could be expected that the crustal movement is caused in the vicinity of the volcano. Actually, this phenomenon has been observed frequently at many volcanoes (Aso[1], Asama[2], Usu[3], Sakurajima[4] and Kilauea[5] etc.). But the modes of this crustal movement vary with the physico-chemical conditions of magma and the geological structure in the vicinity of each volcano. So that the movements are not always similar at each volcano and also at each stage of the volcanic activity. Therefore, for the purpose of studying the mechanism and making the prediction of the volcanic eruption, it is necessary to grasp the characteristics of the mode of crustal movement by continuous geodesic observations and measurements on each volcano.

At the Volcano Sakurajima situated in Kagoshima Bay, Southern Kyushu, the eruption has continued for five years since an out-burst took place at the top of the Minami-Dake on the 13 th of Oct., 1955, although there were the ebb and the flow of the volcanic activity in this period. This volcano repeated great eruptions in the past age. Especially, the greatest eruption on the 12th of Jan., 1914, took place at the two opposite flanks of the Minami-Dake, and a great deal of the leva-streams amounting to 3×10^9 tons flowed out to the eastern and western coast of Sakurajima respectively and covered the area of 24 km^2.

Although Sakurajima is one of the famous volcanoes in the world, a few geophysical informations on this volcano were obtained, because the geophysical instruments for the volcanological routine observation had not been equipped there. Consequently the time of reopening of the volcano activity, we set up many geophysical instruments such as seismometers, tiltmeters, extensometers and tide-gauge etc., and began the seismometric and geodesic observations.

In this paper, the results of the precise levelling and the sea-level observation are discussed and the serial paper will inform the results of the observation of the tilt and the extension of the land.

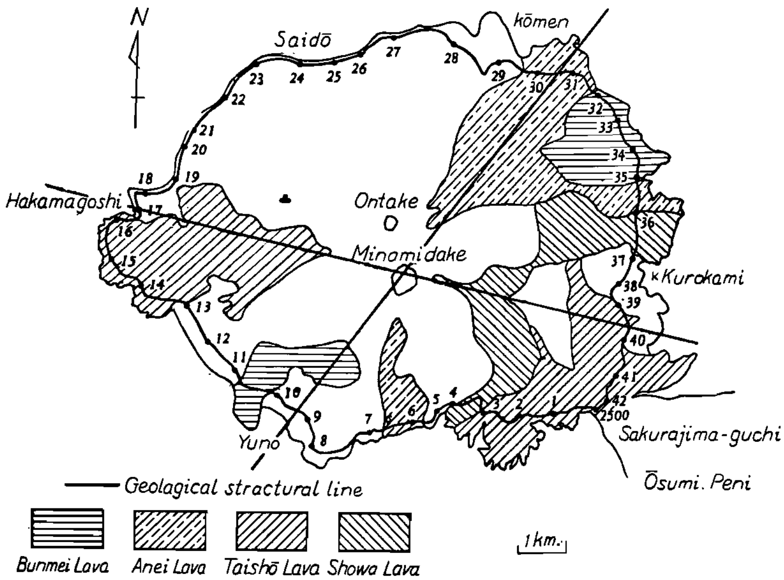


Fig. 1. The position of benchmarks and the distribution of the lava-flow in histry in Sakurajima.

2. Precise levelling

Precies levellings along the surrounding area of Kagoshima Bay were undertaken seven times since 1891, and the relation between the activity of the Volcano Sakurajima and the crustal movement of its surrounding area was discussed by many investigators[6,7,8,9]. However, there seem to be exist no precise levelling data from which one can clarify the exact mode of the crustal movement of the volcano itself, since there has been established no levelling route in Sakurajima before we made.

In Dec., 1956, the levelling route consisting 29 benchmarks was set up from Sakurajima-guchi to Kōmen, via Yuno, Hakamagoshi and Saidō, with total length about 25 km. After that, the new road around Sakurajima was made from Kōmen to Sakurajima-guchi, via Kurokami. Then in Nov., 1958, the levelling route around Sakurajima consisting of 42 benchmarks was also completed, its total length being about 37 km (Fig. 1).

Since Feb., 1957 when the first precised levelling was carried out along this route, four successive ones were done every year till Mar., 1960. The instruments used were the Zeiss A-type level and its staff which was 3 m long and made of invar. The error of the measurement is within the limit of the permission for the first class levelling in Japan.

2-1. Vertical displacement of benchmarks

Assuming that the benchmark No. 2500, at Sakurajima-guchi, is an

Table 1. Values of the vertical displacement of each benchmark.

No. of Benchmark	1957-58	1958-59	1959-60	No. of Benchmark	1957-58	1958-59	1959-60
2500	0 mm.	0 mm.	0 mm.				
1		−2.2	−2.4	22	23.1	−7.1	−1.9
2	−24.1	−7.0	−5.2	23	29.6	−4.1	4.2
3		−6.7	−10.5	24	30.9	−12.0	13.4
4		−1.4	−4.3	25	35.5		20.6
5	−26.4	0.5		26	43.7	−4.7	21.2
6	−27.7	0.3	−1.4	27			24.0
7		−2.7	−4.9	28	16.1	−3.0	17.7
8		−0.5	−11.5	29	41.9	4.9	13.4
9	−25.7	−1.4	−9.6	30			12.5
10		−4.6	−4.9	31			15.3
11	−11.2	−7.5	−5.0	32			10.4
12	−25.9	−9.1	−5.4	33			6.2
13	−8.0	−12.6	−5.5	34			
14		−15.7	−6.4	35			0.5
15		−16.1	−8.9	36			−24.8
16	−2.0	−10.1	−15.0	37			−14.7
17	0.0	−9.9		38			5.8
18		−16.1	−22.3	39			4.1
19	7.5	−10.1	−9.8	40			2.7
20	12.5	−9.8	−7.8	41			−0.6
21	15.0	−12.9	−1.7	42			−0.7

invariable point during the period when four successive levellings were executed, we can obtain the amount of the relative vertical displacement of each benchmark during the respective periods, as shown in Table 1 and Fig. 2, by comparing the results of four successive precise levellings with each other.

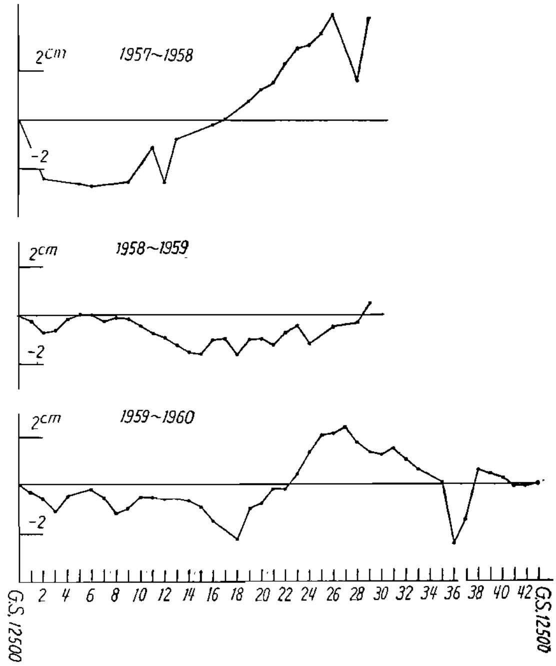


Fig. 2. The vertical displacement of benchmarks in the respective periods.

Now, in order to see the mode of the crustal movement of Sakurajima, let us compare Fig. 2 with the position of the benchmark shown in Fig. 1.

Through all periods we can see that, in the part jointed by Taishō-lava between Sakurajima and Ōsumi peninsula, the former always shows the depression, compared with the latter. On the other hand, in each period we can see the following fact. During 1957-58 the southern part of Sakurajima was depressed and while the northern part was upheaved, and the benchmark No. 12 and No. 28 showed the abnormal depression. During 1958-59, most of the benchmarks, except two or three benchmarks, showed the depression although its amount was smaller than in the previous period, and the amount of the upheaval of two or three benchmarks was also very small. During 1959-60 when the vertical displacement of all benchmarks around Sakurajima was first clarified, the southern part was depressed while the northern part was upheaved, in the same way as in the first period. And new abnormal depressions were found in the neighborhood of the benchmark No. 18 and No. 36.

2-2. Consideration of abnormal depressions

As mentioned above, in the first and the latest periods we found abnormal depressions whose causation is of special improtance to be solve. Before we draw any conclusion on this, we should consider the geological structure of the Volcano Sakurajima.

According to the geological surveies, there are two structural lines in Sakurajima. The one passes across Sakurajima in NEN-SWS direction, and the other in ESE-WNW direction. The former is represented by the group of craterlets in eruptions of Bummei (1968-1476) and Annei (1779), and the latter by the one in the eruptions of Taishō (1914) and Shōwa (1946). The two structural lines intersect each other at the top of Minami-Dake, now being eruption (Fig. 1).

Looking over the abnormal depression under the geological consideration as mentioned above, one can find that every benchmarks showing the abnormal depression are not situated strictly on the geological structural line. That is, the benchmark No. 12 and No. 28 are situated on the western side apart from the structural line of NEN-SWS direction, while No. 18 and No. 36 do on the northern side apart from that of ESE-WNW direction.

Then, it can be considered that the ground in the proximity of the geological structural line is in the more movable circumstance than the very point on the line during this active period of this volcano.

Regarding the striking depression found in the joint between Sakurajima and Ōsumi peninsula, it is difficult to make clear interpretation at present, but one of the reason may be that this zone is the reclaimed ground from the Seto Straits by Taishō-lava and a latent fault passes through there.

The measured fact that the ground easy to move is found by the precise levelling, has a significance not only on the geodesic study but also may yield many informations for the probable prevention of the volcanic disaster.

2-3. Mechanism of the deformation of Sakurajima

The deformation of the ground surface accompanied by the volcanic activity seems to occure by the movement of the pressure center in the vicinity beneath the volcano, probably by that of magma reservior, or the change of the pressure therein.

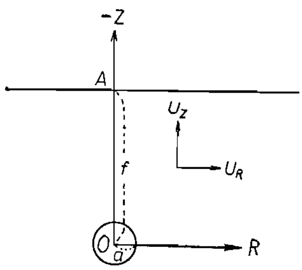


Fig. 3.

Then, we shall consider the deformation caused by them on the basis of the elasticity theory.

According to the theory, the deformation of the semi-infinite elastic body caused by the change of hydrostatic pressure in a small sphere in it, is calculated as follows[10] (Fig. 3).

$$\left.\begin{aligned} U_R &= -\frac{a^3P}{4\mu}\frac{R}{\{(Z+2f)^2+R^2\}^{5/2}}\cdot(5Z^2+14fZ+8f^2-R^2) \\ &\quad +\frac{a^3P}{4\mu}\left(\frac{1}{(Z^2+R^2)^{3/2}}+\frac{R}{\{(Z+2f)^2+R^2\}^{3/2}}\right) \\ U_Z &= \frac{a^3P}{4\mu}\frac{1}{\{(Z+2f)^2+R^2\}^{5/2}}\cdot(7Z^3+38fZ^2+68f^2Z+40f^3+4fR^2 \\ &\quad +ZR^2)+\frac{a^3P}{4\mu}\left(\frac{Z}{(Z^2+R^2)^{3/2}}+\frac{Z+2f}{\{(Z+2f)^2+R^2\}^{3/2}}\right) \end{aligned}\right\} \quad (1)$$

where U_R : displacement in the direction parallel to the surface,
U_Z : displacement in the direction vertical to the surface,
a : radius of the small sphere where the hydrostatic pressure takes place,
P : change of the hydrostatic pressure in the small sphere,
f : depth from the surface to the center of the sphere,
and $\mu(=\lambda)$: Lame's constant.

The equations (1) are the first approximation in the case $a/f \ll 1$.

Now, substituting Z by $-f$ in the equations (1), the displacement at any point on the ground surface is described as

$$\left.\begin{aligned} \Delta d &= \frac{3a^3P}{4\mu}\frac{d}{(f^2+d^2)^{3/2}} \\ \Delta h &= \frac{3a^3P}{4\mu}\frac{f}{(f^2+d^2)^{3/2}} \end{aligned}\right\} \quad (2),$$

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

Δd : displacement in the direction of R-axis on the ground surface,

Δh : vertical displacement on the ground surface.

Comparing the actual deformation measured by successive precise levelling along the coast of Kagoshima Bay before and after the eruption in 1914 with that calculated from the above equation, Mogi[11] pointed out that the pressure center was 10 km just underbeneath the center of the Aira caldera. Then we shall try to explain the mechanism of the deformation of Sakurajima in this active period by using the mode of the vertical displacement observed only in Sakurajima.

First to be assume is the center of the small sphere and then to estimate the change of a^3P/μ. These two are to be determined by a successive approximation in such that the calculation from eq. (2) may coincide as possible with the actual data of the measurment.

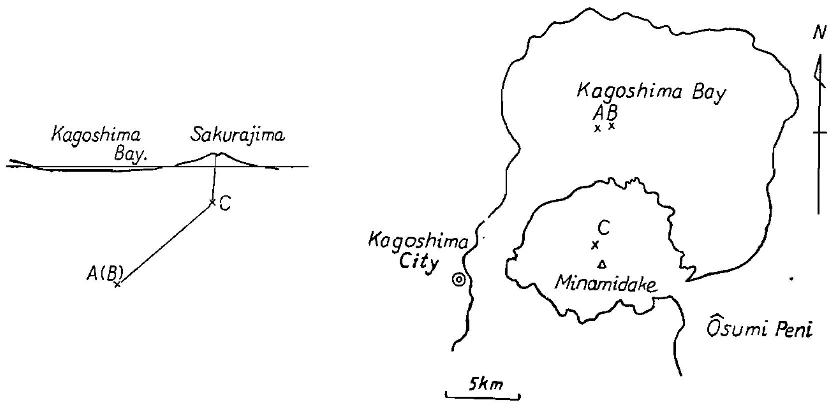


Fig. 4. The position of the pressure center.
A: 1957-58, B: 1958-59 and 1959-60, C: 1959-60.

From the above approximation one can infer that the pressure center was at a place 10 km beneath point A during 1957-58, 10 km beneath point B during 1958-59, and during 1959-60 there were two points, one at B and the other at 3 km beneath point C (Fig. 4).

While, by taking a^3P/μ at point A as an unit we can compare the values at respective periods in the following.

$$(a^2P/\mu)_A=1 \text{ (at 1957-58)},$$
$$(a^3P/\mu)_B=1.06 \text{ (at 1958-59)},$$
$$(a^3P/\mu)_B=1.70 \text{ (at 1959-60)},$$
$$(a^3P/\mu)_C=0.07 \text{ (at 1959-60)}.$$

In Fig. 5 is shown the relation between the measured vertical displacement of each benchmark and calculated displacement.

To account for the deformation occurred during 1959-60 we assumed that the pressure center C was newly created, probably being separated from center B. In calculating the deformation along the above-mentioned model, mathematical discrepancy in superposing the effects of the two centers arises, because of nonlinearity of the equations. However the mutual effects of the two boundary conditions are so small in this case that the superposition is parctically applicable.

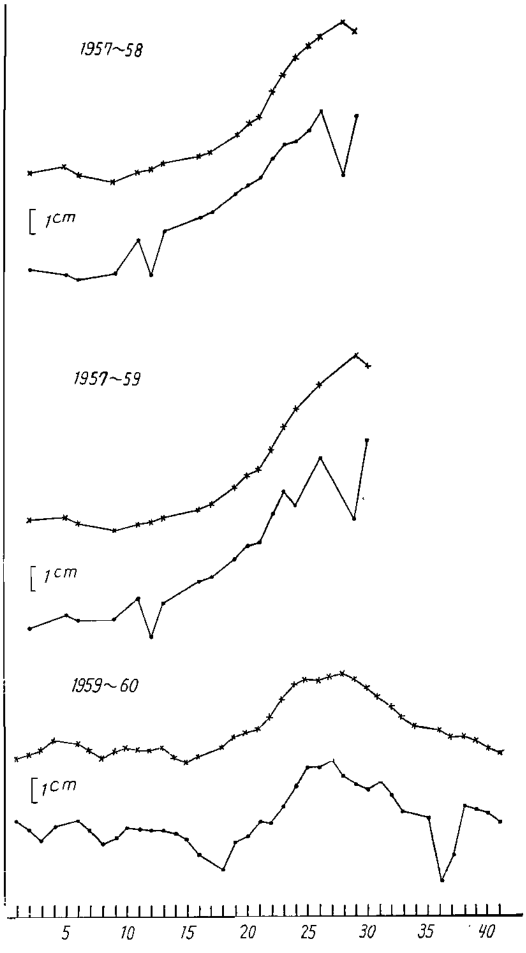
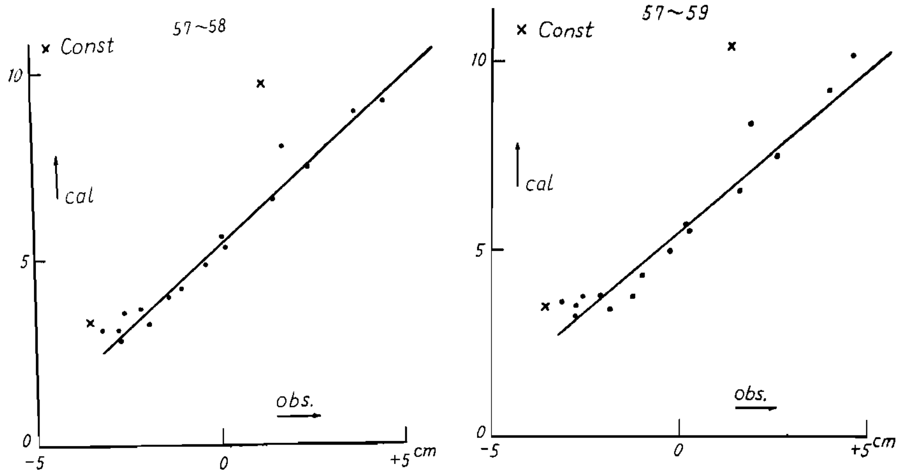


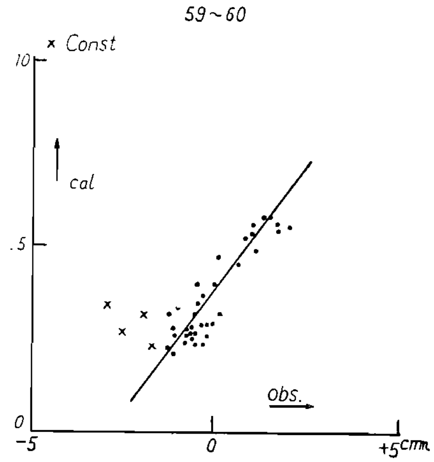
Fig. 5. The relation between the measured and the calculated vertical displacements of benchmarks in Sakurajima in the each period. ● : measured one, × : calculated one.

Briefly speaking the deformation occurred in Sakurajima in all of the periods can be explained sufficiently in the equations on an elastic model.

To make the clear interpretation Fig. 6 is given, in which the relation



(a) (b)



(c)

Fig. 6. The linearity of the relation between the measured and the calculated vertical displacements of benchmarks in Sakurajima.
× are abnormally depressed points.

between the measured and calculated deformation is shown. Quite a reasonable linearity can be found except at several localities which correspond to the places of the benchmarks where the geological structural line is passing near by.

The deviation from the linearity at those places is indeed due to the inadoptability of the elastic model to the pre-existing or latent geological fault or fractured zone.

Nevertheless, the author's data shows that the stress due to the pressure change at the center can well be transmitted without being influenced by the existence of the fractured zone. The fact indicates that these geological irregularities may be only superficial structures compared with that of the general crust, and that the abnormal depression may be the subsidence by some cause about which virtually nothing is known.

In the above procedures we obtained the location of the pressure center and the change of a^3P/μ which changed from time to time and from place to place. Namely, in the first period the location of the pressure center was 10 km in depth under the center of the Aira caldera, in the middle period it was 10 km in depth under the place being about 1 km eastwards away from the location in the first period, and in the last period the centers were both at the same location in the middle period and at place 3 km below the Kita-Dake. On the other hand, value of a^3P/μ increased with time.

3. Sea-level observation

The vertical land displacement near the sea-side is also to be examined by the observation of the variation of the mean sea-level, for which it is usual to use the tide-gauge. But it is not safe to presume directly the change of the mean sea-level at only one station as the displacement, because the mean sea-level is greatly influened by the local atmospheric pressure or

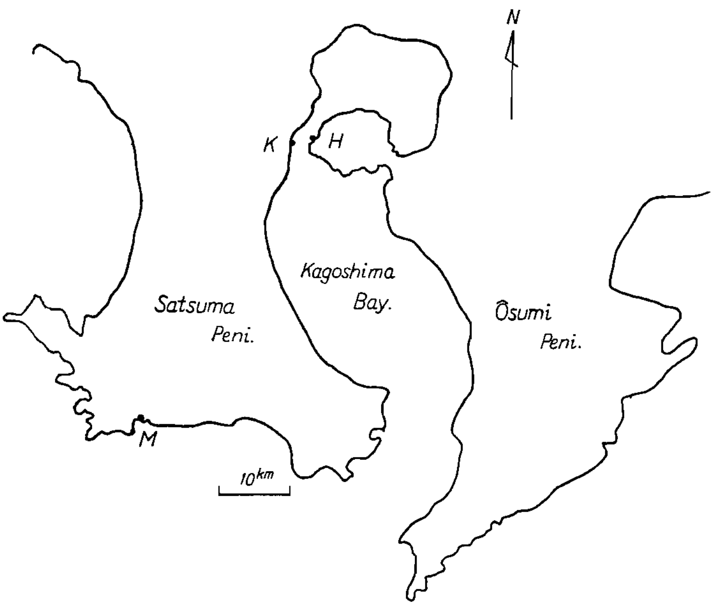


Fig. 7. The locations of the tidal gauge stations.
H : Hakamagoshi. K : Kagoshima. M : Makurazaki.

other factors. If the observations of the sea-level are carried out at two stations, situated so close together that these effects are regarded as equal, the relative land movement between two stations could be found more accurately from the difference in the mean sea-level at both stations.

Since July, 1958, the observation of the change of sea-level by the Roll type tide-gauge has been carried out at Hakamagoshi Harbor in Sakurajima.

Table 2. The monthly mean values of the sea-level at each station, and their differences among two stations.

Month	Hakamagoshi	Kagoshima	Makurazaki	K-H	M-K
1958	cm.	cm.	cm.	cm.	cm.
July	209.2	209.0	275.9	−0.2	66.9
Aug.	203.2	210.8	276.3	7.6	65.5
Sept.	220.6	223.5	289.8	2.9	66.3
Oct.	204.8	211.8	277.5	7.0	65.7
Nov.	190.3	205.9	272.5	15.6	66.6
Dec.	182.5	193.7	261.3	11.2	67.6
1958					
Jan.		186.5	253.1		66.6
Feb.	173.4	187.4	260.5	14.0	73.1
Mar.	167.5	186.1	255.4	18.6	69.3
Apr.	172.4	194.6	267.0	22.2	72.4
May	177.0	201.6	271.8	24.6	70.2
June	189.3	215.9	284.7	26.6	68.8
July	188.5	219.7	287.2	31.2	67.5
Aug.	181.6	219.7	286.9	38.1	67.2
Sept.	174.4	221.8	283.1	47.4	61.3
Oct.	168.0	223.3	288.2	55.3	64.9
Nov.	148.4	205.7	274.8	57.3	69.1
Dec.	136.8	198.2	268.8	61.4	70.6
1960					
Jan.	145.9	190.9	258.7	45.0	67.8
Feb.	136.9	188.1	252.3	51.2	64.2
Mar.	141.3	195.0	265.8	53.7	70.8
Apr.	138.2	192.8	262.6	54.6	69.8
May	142.8	200.6		57.8	
June	151.7	211.2		59.5	
July	146.7	206.5		59.8	
Aug.	162.7	225.5		62.8	

Fortunately, the observation has also been carried out as the routine work of Kagoshima Meteological Observatory at Kagoshima Harbor, which is apart about 4 km westwards from Hakamagoshi Harbor.

The monthly mean values of the sea-levels at both stations and the differences of these values are showm in Table 2 and Fig. 8. We can see that during the last two years the ground of Hakamagoshi upheaved about 60 cm respective to Kagoshima.

Comparing monthly mean values of the sea-level at Kagoshima Harbor with that at Makurazaki Harbor, about 42 km south-west of Kagoshima Harbor, it was found that the difference between them has scarecely changed during the last two years as shown in Fig. 8.

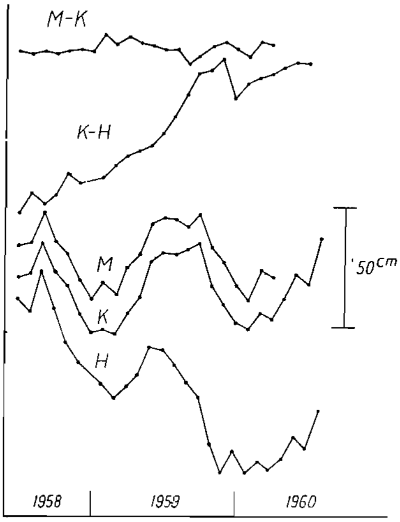


Fig. 8. The changes of the monthly mean values of the sea-level at each station, and the changes of the differences of these values between two stations.
H Hakamagoshi. K Kagoshima.
M . Makurazaki.

From these facts, we can consider that the upheaval of Sakurajima was caused by the incressure of the pressure in the magman reservior in this active period. But we can not explain the relative land movement between Kagoshima and Hakamagoshi by the elasticity theory as used in 2-3, because the calculation does not give the actual amounts obtained by observations of the sea-levels. Therefore, there may be some unknown discontinuity in the crustal structure between the two stations.

4. Summary

We have carried out the studies on the crustal movement accompanied by the volcanic activity of Sakurajima. In this paper, results of the precise levellings and the mean sea-level observations were discussed.

According to these results, the following facts are to be concluded.

1) The ground in the neighborhood of the geological structural line is

easy to move during this active period of the valcano, so that the bench-marks near this line shows the abnormal depression.

2) The position of the pressure center and the change of the a^3P/μ in eq. (1) in each period, are able to be estimated on the basis of the elasticity theory. The supposed position of the pressure center in the first period, was 10 km in depth under the center of the Aira caldera, in the second period was 10 km in depth under the place being about 1 km eastwards away from the first center, and in the last period was at two centers, the one being the same as the second center and the other at Kita-Dake with depth 3 km. The estimated values of a^3P/μ increased with time.

3) Comparison between the mean sea-level at Kagoshima and that at Hakamagoshi Harbor shows that the former place upheaved about 60 cm relative to the latter during July, 1958–Aug., 1960. From this fact it may be presumed that the pressure in magma reservior increased in this active period.

This studies may give some data on which the mechanism of the eruption could be estimated and also the activity could be predicted.

Acknowledgements

The writer wishes to expreses his cordinal thanks to Prof. Kenzo Sassa of Kyoto University for his kind guidance and encouragements throughout the study. The writer is greatly indebted to the kind help shown by Mr. Shunzo Nakamura during the observation. The writer's gratitude is also to Kagoshima Meteological Observatory who kindly effered the data of the sea-level.

Reference

1) K. Sassa : Micro-seismetric Study on Eruptions of the Volcano Aso ; Memoirs of the College of Science Kyoto Imperial University, Vol. 14, No. 1, 1936.

2) R. Takahashi and T. Minakami : Tilt Observation during the Activities of Volcano Asama ; Bulletin of the Earthquake Research Institute, Vol. 15, 1937.

3) F. Omori : The Use-San Eruption and Earthquake and Elevation Phenomena ; Bulletin of the Imperial Earthquake Investigation Committee, Vol. 5, 1911–1913.

4) F. Omori . The Sakura-jima Eruptions and Earthquakes ; Bulletin of the Imperial Earthquake Investigation Committee, Vol. 8, 1914–1922.

5) A. E. Jones : Ground-surface Displacements and Earthquakes at Kilauea, Hawaii, First Half-year, 1935 ; Bulletin of the Seismological Society of America, Vol. 27,

1937.
6) F. Omori : loc. cit. 4)
7) C. Tsuboi : Block Movements as revealed by means of Precise Levellings in Some Earthquake Districts of Japan ; Bulletin of the Earthquake Research Institute, Vol. 7, 1929. Comparison of the Modes of the Vertical Deformations of the Earth's Crust in Same District during Different Timc Intervals ; Bulletin of the Earthquake Research Institute. Vol. 10, 1932.
8) N. Miyabe : Deformation of the Earth's Crust in the Neighbourhood of Sakurajima ; Bulletin of the Earthquake Research Institute, Vol. 12, 1934.
9) K. Mogi : Relations between the Eruptions of Various Volcanoes and the Deformations of the Ground Surface around Them ; Bulletin of the Earthquake Research Institute, Vol. 36, 1958.
10) N. Yamakawa : On the Strain Produced in a Semi-infinite Elastic Solid by an Interior Source of Stress ; Zisin (Jour. Seis. Soc. Japan), [ii] Vol. 8, 1955.
11) K. Mogi : loc. cit. 9)

Publications of the Disaster Prevention Research Institute

The Disaster Prevention Research Institute publishes reports of the research results in the form of bulletins. Publications not out of print may be obtained free of charge upon request to the Director, Disaster Prevention Research Institute, Kyoto University, Kyoto, Japan.

Bulletins :

No. 1 On the Propagation of Flood Waves by Shoitiro Hayami, 1951.
No. 2 On the Effect of Sand Storm in Controlling the Mouth of the Kiku River by Tojiro Ishihara and Yuichi Iwagaki, 1952.
No. 3 Observation of Tidal Strain of the Earth (Part I) by Kenzo Sassa, Izuo Ozawa and Soji Yoshikawa. And Observation of Tidal Strain of the Earth by the Extensometer (Part II) by Izuo Ozawa, 1952.
No. 4 Earthquake Damages and Elastic Properties of the Ground by Ryo Tanabashi and Hatsuo Ishizaki, 1953.
No. 5 Some Studies on Beach Erosions by Shoitiro Hayami, Tojiro Ishihara and Yuichi Iwagaki, 1953.
No. 6 Study on Some Phenomena Foretelling the Occurrence of Destructive Earthquakes by Eiichi Nishimura, 1953.
No. 7 Vibration Problems of Skyscraper. Destructive Element of Seismic Waves for Structures by Ryo Tanabashi, Takuzi Kobori and Kiyoshi Kaneta, 1954.
No. 8 Studies on the Failure and the Settlement of Foundations by Sakurō Murayama, 1954.
No. 9 Experimental Studies on Meteorological Tsunamis Traveling up the Rivers and Canals in Osaka City by Shoitiro Hayami, Katsumasa Yano, Shohei Adachi and Hideaki Kunishi, 1955.
No.10 Fundamental Studies on the Runoff Analysis by Characteristics by Yuichi Iwagaki, 1955.
No.11 Fundamental Considerations on the Earthquake Resistant Properties of the Earth Dam by Motohiro Hatanaka, 1955.
No.12 The Effect of the Moisture Content on the Strength of an Alluvial Clay by Sakurō Murayama, Kōichi Akai and Tōru Shibata, 1955.
No.13 On Phenomena Forerunning Earthquakes by Kenzo Sassa and Eiichi Nishimura, 1956.
No.14 A Theoretical Study on Differential Settlements of Structures by Yoshitsura Yokoo and Kunio Yamagata, 1956.
No.15 Study on Elastic Strain of the Ground in Earth Tides by Izuo Ozawa, 1957.
No.16 Consideration on the Mechanism of Structural Cracking of Reinforced Concrete Buildings Due to Concrete Shrinkage by Yoshitsura Yokoo and S. Tsunoda. 1957.
No.17 On the Stress Analysis and the Stability Computation of Earth Embankments by Kōichi Akai, 1957.
No.18 On the Numerical Solutions of Harmonic, Biharmonic and Similar Equations by the Difference Method Not through Successive Approximations by Hatsuo Ishizaki, 1957.
No.19 On the Application of the Unit Hydrograph Method to Runoff Analysis for Rivers in Japan by Tojiro Ishihara and Akiharu Kanamaru, 1958.
No.20 Analysis of Statically Indeterminate Structures in the Ultimate State by Ryo Tanabashi, 1958.
No.21 The Propagation of Waves near Explosion and Fracture of Rock (I) by Soji Yoshikawa, 1958.
No.22 On the Second Volcanic Micro-Tremor at the Volcano Aso by Michiyasu Shima, 1958.
No.23 On the Observation of the Crustal Deformation and Meteorological Effect on It at Ide Observatory and On the Crustal Deformation Due to Full Water and Accumulating Sand in the Sabo-Dam by Michio Takada, 1958.
No.24 On the Character of Seepage Water and Their Effect on the Stability of Earth Embankments by Kōichi Akai, 1958.
No.25 On the Thermoelasticity in the Semi-infinite Elastic Soid by Michiyasu Shima, 1958.
No.26 On the Rheological Characters of Clay (Part 1) by Sakurō Murayama and Tōru

Shibata, 1958.

No.27 On the Observing Instruments and Tele-metrical Devices of Extensometers and Tiltmeters at Ide Observatory and On the Crustal Strain Accompanied by a Great Earthquake by Michio Takada, 1959.

No.28 On the Sensitivity of Clay by Shinichi Yamaguchi, 1959.

No.29 An Analysis of the Stable Cross Section of a Stream Channel by Yuichi Iwagaki and Yoshito Tsuchiya, 1959.

No.30 Variations of Wind Pressure against Structures in the Event of Typhoons by Hatsuo Ishizaki, 1959.

No.31 On the Possibility of the Metallic Transition of MgO Crystal at the Boundary of the Earth's Core by Tatsuhiko Wada, 1960.

No.32 Variation of the Elastic Wave Velocities of Rocks in the Process of Deformation and Fracture under High Pressure by Shogo Matsushima, 1960.

No.33 Basic Studies on Hydraulic Performances of Overflow Spillways and Diversion Weirs by Tojiro Ishihara, Yoshiaki Iwasa and Kazune Ihda, 1960.

No.34 Volcanic Micro-tremors at the Volcano Aso by Michiyasu Shima, 1960.

No.35 On the Safety of Structures Against Earthquakes by Ryo Tanabashi, 1960.

No.36 On the Flow and Fracture of Igneous Rocks and On the Deformation and Fracture of Granite under High Confining Pressure by Shogo Matsushima, 1960.

No.37 On the physical properties within the B-layer deduced from olivine-model and on the possibility of polymorphic transition from olivine to spinel at the 20° Discontinuity by Tatsuhiko Wada, 1960.

No.38 On Origins of the Region C and the Core of the Earth ——Ionic-Intermetallic-Metallic Transition Hypothesis—— by Tatsuhiko Wada, 1960.

No.39 Crustal Stucture in Wakayama District as Deduced from Local and Near Earthquake Observations by Takeshi Mikumo, 1960.

No.40 Earthquake Resistance of Traditional Japanese Wooden Structures by Ryo Tanabashi, 1960.

No.41 Analysis With an Application to Aseismic Design of Bridge Piers by Hisao Goto and Kiyoshi Kaneta, 1960.

No.42 Tilting Motion of the Ground as Related to the Volcanic Activity of Mt. Aso and Micro-Process of the Tilting Motion of Ground and Structure by Yoshiro Itō, 1961.

No.43 On the Strength Distribution of the Earth's Crust and the Upper Mantle, and the Distribution of the Great Earthquakes with Depth by Shogo Matsushima, 1961.

No.44. Observational Study on Microseisms (Part 1) by Kennosuke Okano, 1961.

No.45. On the Diffraction of Elastic Plane Pulses by the Crack of a Half Plane by Michiyasu Shima, 1961.

No.46 On the Observations of the Earth Tide by Means of Extensometers in Horizontal Components by Izuo Ozawa, 1961.

No.47 Observational Study on Microseisms (Part 2) by Kennosuke Okano, 1961.

No.48 On the Crustal Movement Accompanying with the Recent Activity on the Volcano Sakurajima (part 1) by Keizo Yoshikawa, 1961.

Bulletin No. 48 Published August, 1961

昭和 36 年 8 月 25 日 印 刷
昭和 36 年 8 月 31 日 発 行

編輯兼発行者 京都大学防災研究所

印刷者 山代多三郎
京都市上京区寺之内通小川西入

印刷所 山代印刷株式会社