DISASTER PREVENTION RESEARCH INSTITUTE
BULLETIN No. 50 FEBRUARY, 1962

ON THE CRUSTAL MOVEMENT ACCOMPANYING WITH THE RECENT ACTIVITY OF THE VOLCANO SAKURAJIMA (PART 2)

BY

KEIZŌ YOSHIKAWA

KYOTO UNIVERSITY, KYOTO, JAPAN

DISASTER PREVENTION RESEARCH INSTITUTE
KYOTO UNIVERSITY
BULLETINS

Bulletin No. 50 February, 1962

On the Crustal Movement Accompanying with the Recent Activity of the Volcano Sakurajima (Part 2)

By

Keizo YOSHIKAWA

On the Crustal Movement Accompanying with the Recent Activity of the Volcano Sakurajima (Part 2)

By

Keizo YOSHIKAWA

1. Introduction

The routine observation by tiltmeter and extensometer is very important for the investigation of crustal deformation accompanying with the activity of earthquake and volcano as in the case of the measurement by precise levelling and triangulation.

From the precise levelling and triangulation the crustal deformation in a wide region will be studied, but the total process of the deformation will be difficult to get since the the measurement is usually carried out at a certain interval. On the other hand, from the routine observation by tiltmeter and extensometer the continuous process will be studied, however, it often happens that the results obtained can not be regarded as the crustal deformation corresponding to a total region, due to the local deformation of the place where the instruments are put.

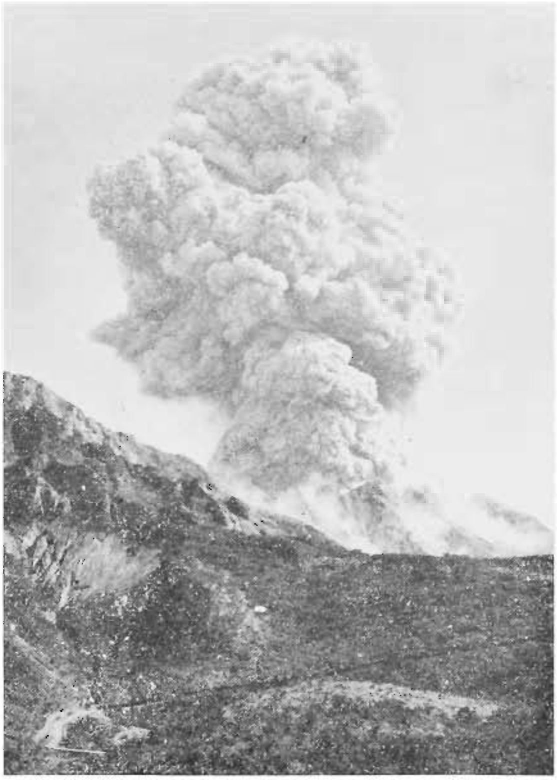
Therefore, the routine observations by tiltmeter and extensometer in as many places as possible are preferable for the investigation of the crustal deformation along with that of precise levelling and triangulation.

In the previous paper (part 1), the crustal deformation of the Volcano Sakurajima, obtained from the measurements of four successive precise levellings during 1957-1960 and the results of the observation of the change of mean sea-level during July, 1958—Aug., 1960 was reported, and also the position of pressure center of the volcano and the variation in the pressure center were presumed by analying these results based on the theory of elasticity.

In this paper, the results of routine observation by tiltmeter and extensometer at two stations are reported, and the results are compared with that of precise levellings, and the relation between the volcanic activity and the results are also discussed.

2. General aspect of the volcanic activity

Since 13th Oct., 1955, the eruptions more than a thausand have taken place in this volcano, and the eruption cloud has been often jeted to the height of thausands of meters in the air. In the usual eruption the ashes and the fine sands with gases were ejected, whereas in the extreme case a massive hot-lava weighting a few tones was sometimes thrown away about 2 km from the crater.


Phot. 1. Eruption cloud reached 3,000 m in height on the occasion of the eruption 30th of Oct., 1958.

The earthquake accompanying the eruption of volcano is generally called the eruption earthquake. In order to study the general aspect of the volcanic activity in this period, the maximum amplitude of the eruption earthquake, which have been recorded by Wiechert-Seismograph at Kagoshima Meteological Observatory[1] 10 km apart from the crater in the west, was investigated as a important factor.

In Fig. 1, the daily sum of the maximum amplitudes of the eruption earthquake is shown. From this figure we can see that there are active and quiescent periods, and also that the activity in 1960 is most remarkable.

In order to estimate roughly how the variation of discharged energy

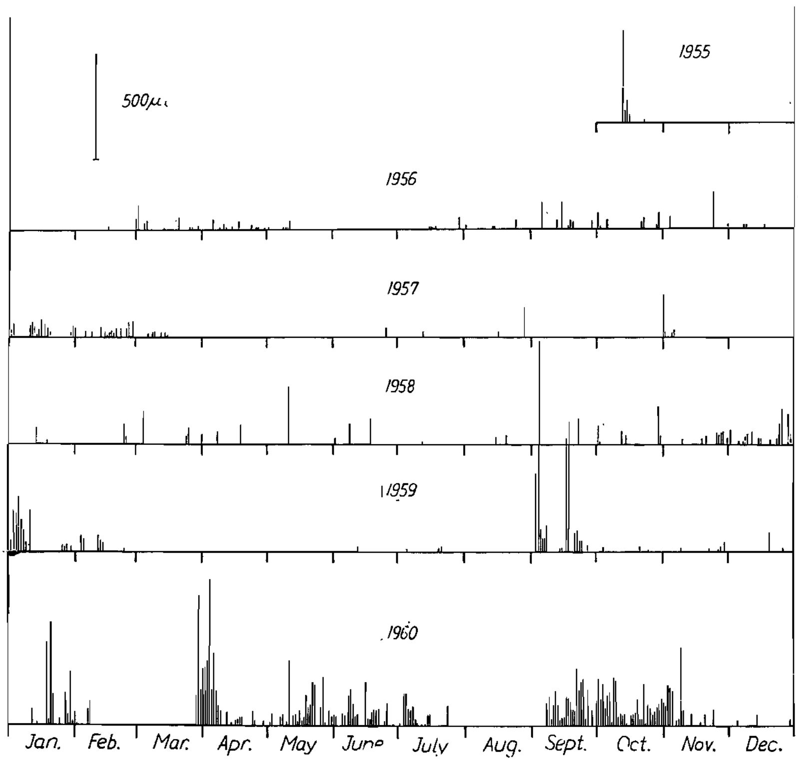


Fig. 1. Daily sum of maximum amplitude of eruption earthquakes recorded by Wiechert-Seismograph at Kagoshima Meteological Observatory.

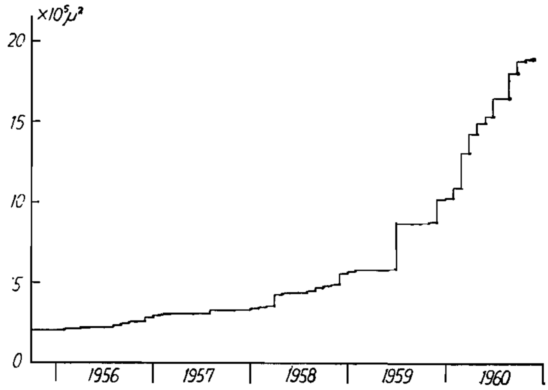


Fig. 2. Successive accumulation of the square of maximum amplitude of eruption earthquake.

by eruptions has been changed with time, the successive sums of the square of maximum amplitude are taken as show in Fig. 2, and it is found that the amount of discharged energy increases with time.

It is very interesting that this fact coincides qualitatively with the result obtained in part 1, that is, the increase of the potential in the pressure center.

3. Instruments and the places of observation

For the purpose of observing the crustal deformation by tiltmeter and extensometer, two gallerys were selected as the observation stations. One is situated at Hakamagoshi in Sakurajima being 5.6 km apart in WNW from the crater, and the other at Hiyamizu-chō in Kagoshima city being 11 km apart in WNW from it (Fig. 3). The surrounding rock of both gallerys is tuff containing pumice called "Shirasu" Instruments are set far away from the entrance of the gallery and deep from the ground sur-

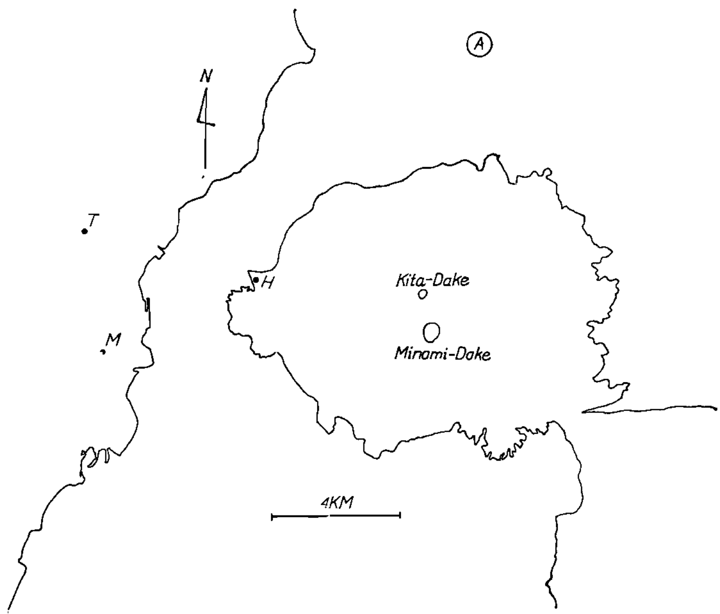


Fig. 3. Position of observating station.
H : Hakamagoshi. T : Hiyamizu. M : Kagoshima Meteological Observatory.
A : Center of Aira caldera.

face. As the variation of temperature in these places is within 3°C throughout the year, the unfavourable effects of temperature on the instruments may be disregarded.

At Hakamagoshi observation station, two components of horizontal pendulum tiltmeters and two components of Sassa type extensometers and a vertical component of bar-extensometer are set. At Hiyamizu, two components of tiltmeters and Sassa type extensometers are set.

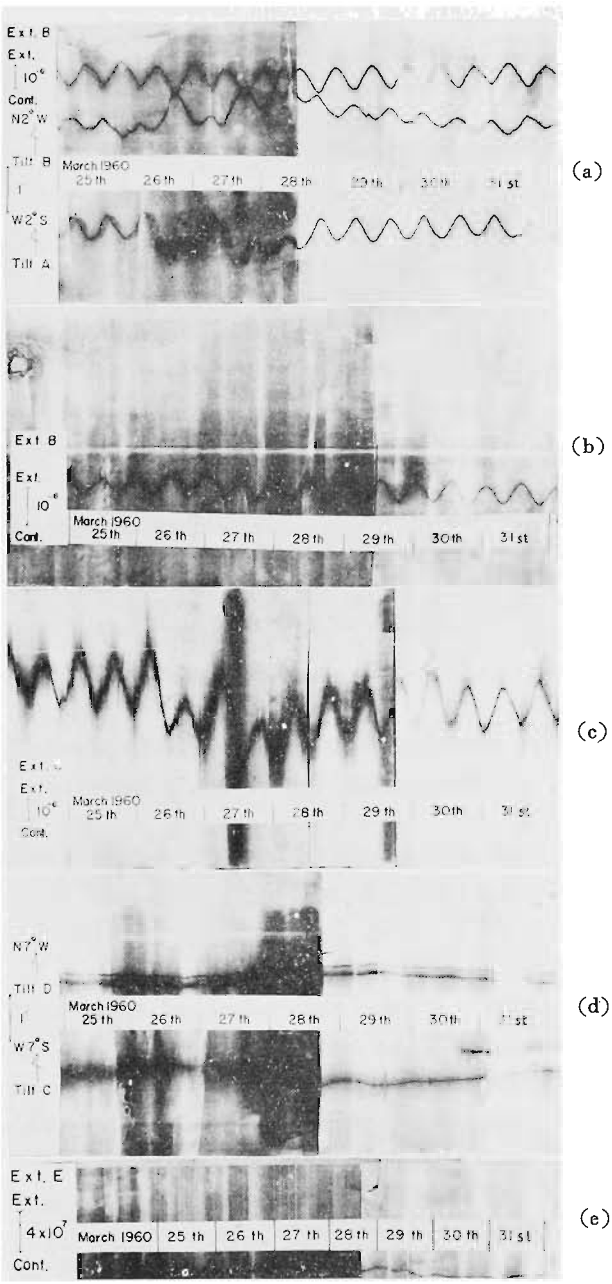
The specifications of every instruments are given as follows:

Instrument	Azimuth	Sensitivity	Location
Tiltmeter A	W2°S	0.025″/mm	Hakamagoshi
Tiltmeter B	N74°W	0.025″/mm	Hakamagoshi
Extensometer A	N74°E	3.0×10^{-8}/mm	Hakamagoshi
Extensometer B	N17°W	3.2×10^{-8}/mm	Hakamagoshi
Extensometer C	Vertical	3.5×10^{-8}/mm	Hakamagoshi
Tiltmeter C	W7°S	0.025″/mm	Hiyamizu
Tiltmeter D	N7°W	0.025″/mm	Hiyamizu
Extensometer D	N76°E	1.5×10^{-8}/mm	Hiyamizu
Extensometer E	N14°W	1.3×10^{-8}/mm	Hiyamizu

4. Effect of the oceanic tide

A record obtained by each instrument is shown in photo. 2(a), (b), (c), (d) and (e).

The records at Hakamagoshi facing the coast are of sinusoidal type, which appears to be caused by the oceanic tide. On the other hand, the records at Hiyamizu, located apart from the coast, show not so remarkably the effect of the oceanic tide as those at Hakamagoshi. In order to study the origin of this crustal deformation of harmonic type, these records are compared with that of tide-guage at Hakamagoshi Harbour. As shown in Fig. 4, the phase lag between the oceanic tide and the crustal deformation is about 4 hours and a half, and when the oceanic tide is high, the land is tilted in the opposite direction to the coast, contracted in vertical and extended in horizontal. This fact shows that the harmonic crustal deformation is likely to be related with the variation of the permeation of sea-water owing to oceanic tide.



Phot. 2. Records obtained by each instrument.

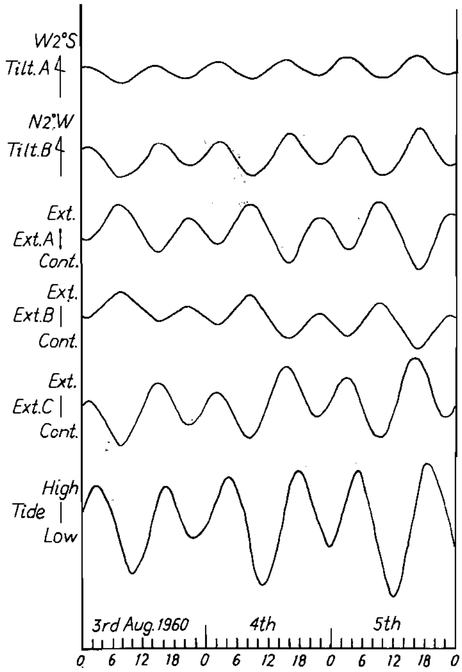


Fig. 4. Relation between the crustal deformation and the oceanic tide.

5. General aspect of the crustal deformation and the relations with the volcanic activity

The daily mean values deduced from the records of each instrument are shown graphycally in Fig. 5 and Fig. 6.

a) Curves A and B in Fig. 5 representing the results of tilt observation at Hakamagoshi.

In general, the curve A shows the gradual and monotone tilt downwards E2°N, while the curve B shows sometimes the conspicuous inversion of the tilt direction, especially the rapid tilt of about 10″ downwards S2°E in the latter quarter of 1960. On examining the records in detail, we can often recognize a small amount of variation with short period.

b) Curves C and D in Fig. 5 representing the results of the tilt observation at Hiyamizu.

The curve C shows a monotone tilt downwards W7°S till Sept., 1960, excluding the earlier period of this observation and the period from Dec., 1959 to Mar., 1960 in which an inversion of tilt direction takes place, and after that it shows a rapid tilt of about 10″ downwards E7°N is found. The curve D shows a considerable tilt downwards N7°W in the earlier period of this observation, followed a slight tilt downwards S7°E, although a little inversion of its direction is sometimes recognized. The variations with short period in both curves are found not so frequently as in curves A and B.

c) Curves A, B and C in Fig. 6 representing the results of the extensometer observed at Hakamagoshi.

Curves A and B show a large contraction in every rainy season, while curve C shows a large extention in the same season of 1960. The effect related with rainfall will be discussed in the appendix. Apart from these variations, the curve A shows small variation, excluding the contration in 1958, and the curve B shows a monotone contraction, while the curve C shows the variation of short period more frequently than in the case of curves A and B.

d) Curves D and E in Fig. 6 representing the results of the extensometer observed at Hiyamizu-chō.

Both curves do not show a large contraction in rainy season, and also the variation is very small throughout the periods.

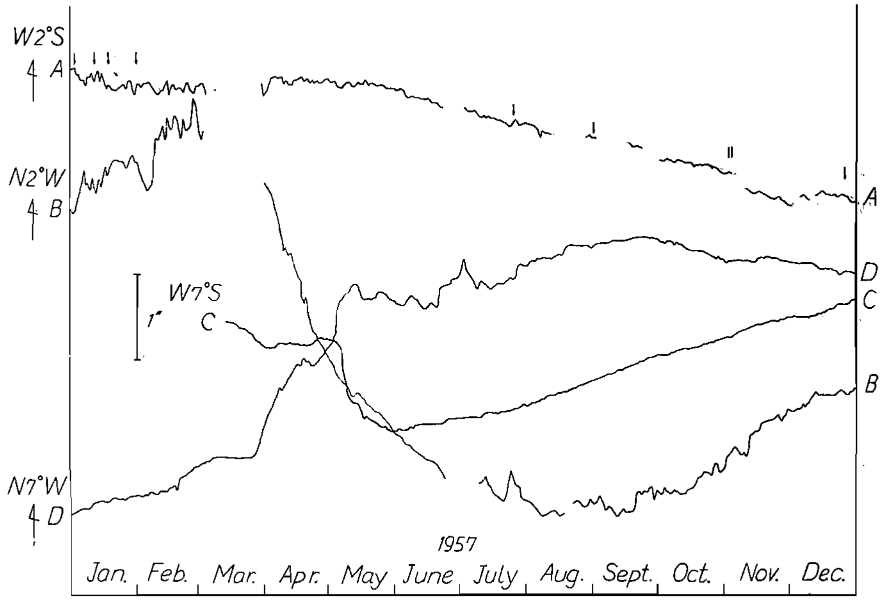
Considering the relation between the results above described and the volcanic activity, the following relations are obtained :

a) Comparing the curve B in Fig. 5 with Fig. 1, a close relation appears to be held between the inversion of tilt direction and the volcanic activity. That is, in the active period it shows the tilt downwards N2°W, while in the rest period the tilt downwards S2°E.

b) The particular variations, marked by the arrows on the curve A and B in Fig. 5, are considered as the forerunning abnormal tilt of the eruption which will be described in Chap. 7.

c) The inversion of tilt direction in the interval Dec., 1959–Mar., 1960 as shown the curve C of Fig. 5, may have a relation with the activity in Jan.-Mar., 1960 in which the largest amount of hot-lava in this active period rose to the old crater of Minami-Dake.

d) The rapid tilt of 10″ downwards S2°W at Hakamagoshi and the rapid tilt of 10″ downwards E7°N at Hiyamizu were occurred at the same time in the latter quarter of 1960. This fact is very interesting to presume



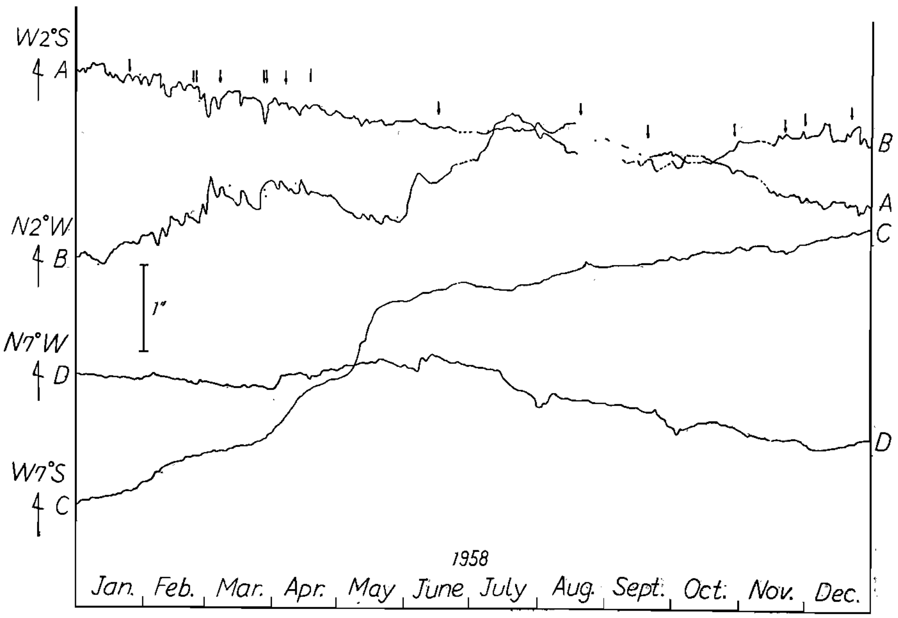
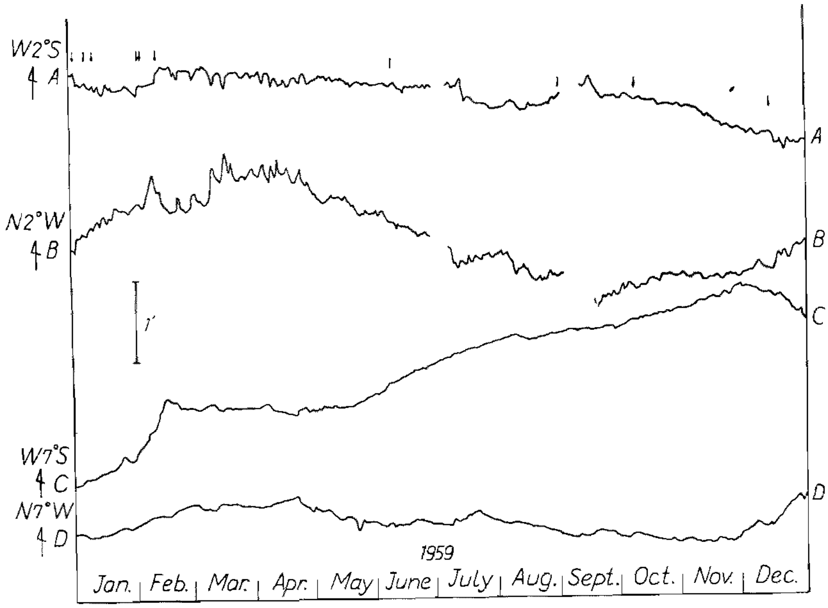
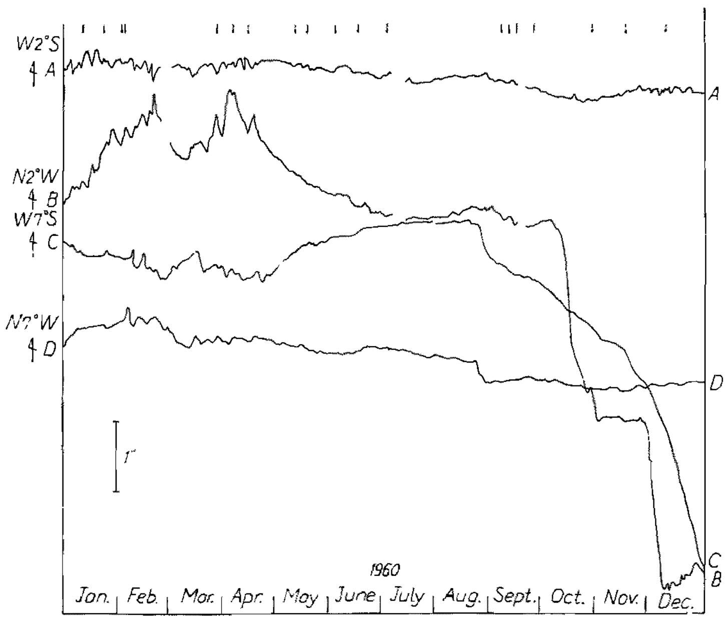


Fig. 5. Results of the tilt observation.

A : W2°S component at Hakamagoshi.
B : N2°W component at Hakamagoshi.





C : W7°S component at Hiyamizu.
D : N7°W component at Hiyamizu.

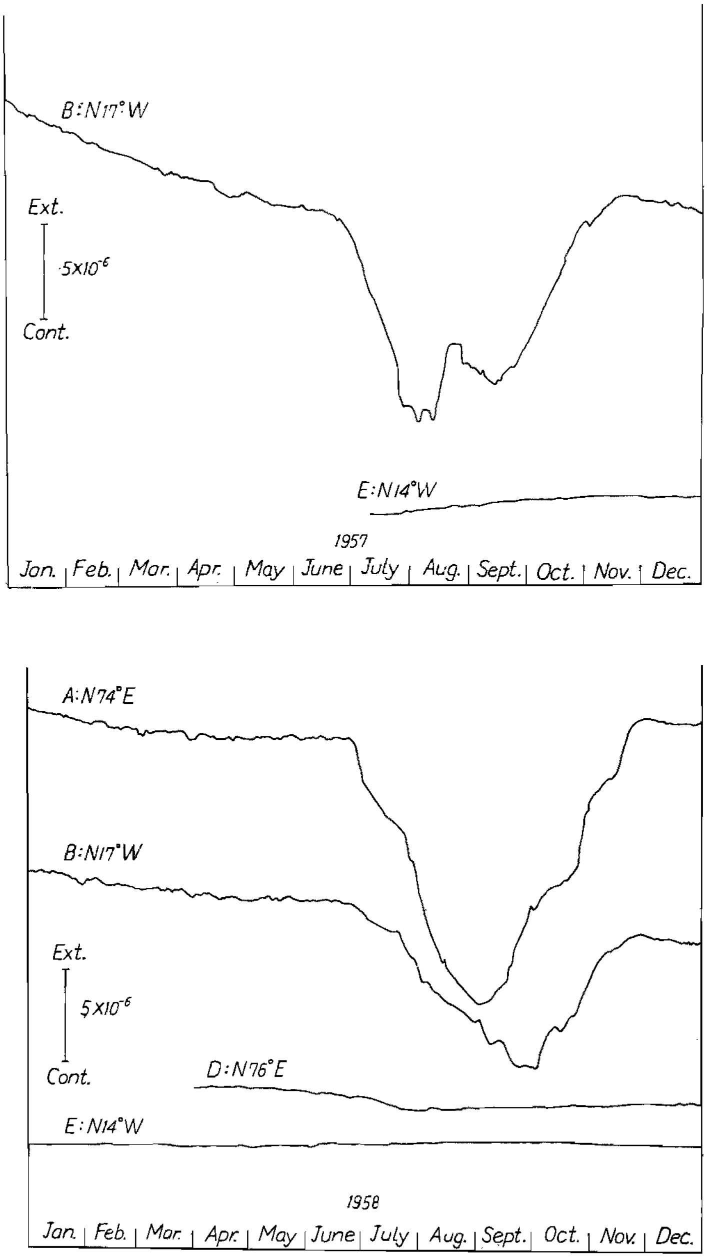
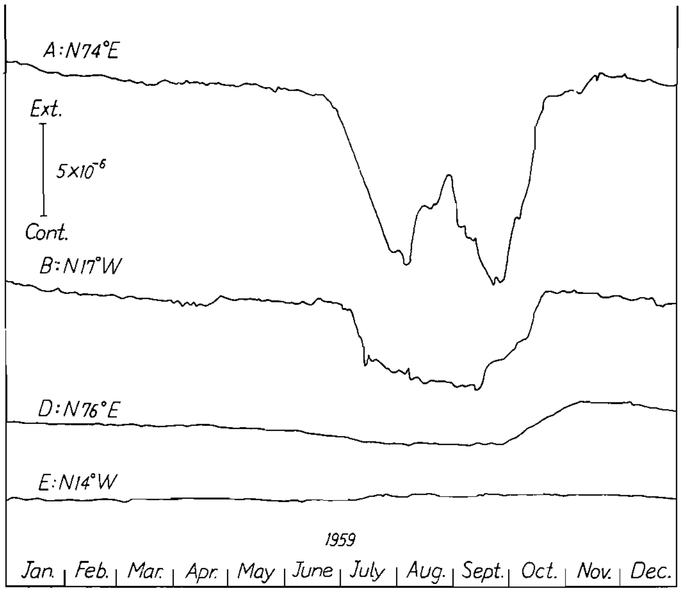
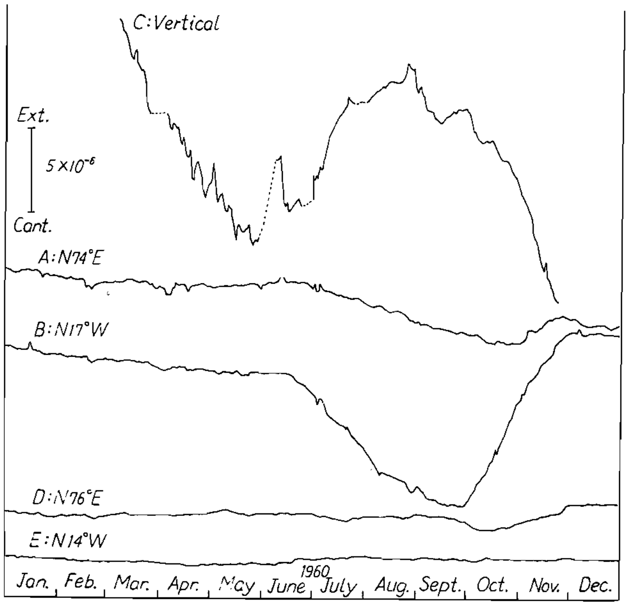


Fig. 6. Results of the extention and contraction observation.

A : N74°E component at Hakamagoshi.

B N17°W component at Hakamagoshi.





C Vertical component at Hakamagoshi.

D N76°E component at Hiyamizu.

E : N14°W component at Hiyamizu.

the activity of volcanic.

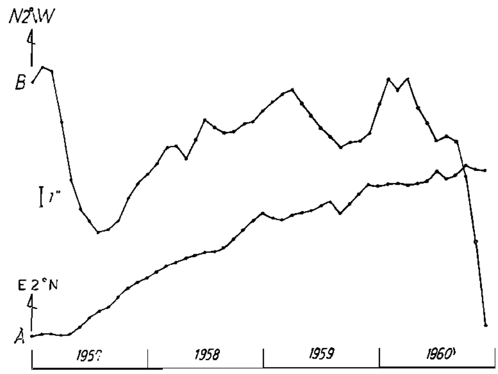


Fig. 7. (a) Monthly mean values of the tilt at Hakamagoshi.

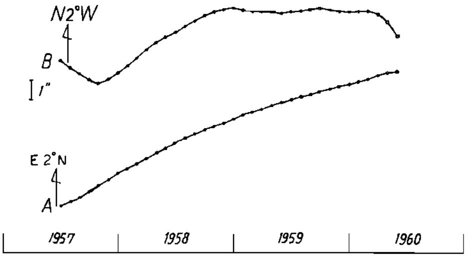


Fig. 7. (b) Secular variation of the tilt at Hakamagoshi.

e) From the records of extensometer shown in Fig. 6, the relation between the strain variation and the activity is not remarkable, although only the vertical component at Hakamagoshi which was observed from Mar., 1960, seems to have some relation.

6. Secular variation in comparison with the results of precise levelling

To find the secular variation of the crustal deformation, the overlapping mean of 13 months are evaluated. Let n_{p+i} ($i=\pm 1, 2, \ldots, 6$) be monthly mean values, the overlapping mean N_p becomes as follows:

$$N_p = \frac{n_{p-6}+n_{p-5}+\cdots\cdots+n_p+\cdots\cdots+n_{p+5}+n_{p+6}}{13}.$$

The series of N_p thus obtained may be considered as the secular variation, because most of the annual variation are eliminated from the series of the monthly mean values.

The monthly mean values and the secular variations are shown graphycally in Fig. 7, Fig. 8, Fig. 9 and Fig. 10, and the secular variations

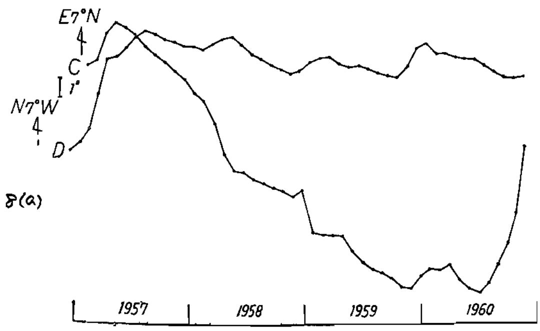


Fig. 8. (a) Monthly mean values of the tilt at Hiyamizu.

of tilts at both stations are represented vectorically in Fig. 11 and Fig. 12.

The secular variation of tilt at Hakamagoshi is about 2″ downwards SE direction during July–Nov., 1957, about 5.5″ downwards NE direction during Nov., 1957–Jan., 1959, about 2″ downwards E during Jan., 1958–Mar., 1960, and about 1″ downwards S10°E since then.

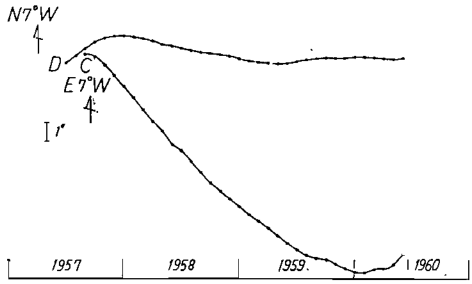


Fig. 8. (b) Secular variations of the tilt at Hiyamizu.

The secular variation of tilt at Hiyamizu is about 5.7″ downwards W20°S till Feb., 1960 and after that it returns about 0.5″ to the inverse direction.

The secular variation at Hakamagoshi shows a monotone contraction in N17°W throughout this period, amounting to 6×10^{-6}, and the variation of strain is below 1×10^{-6} in N74°E direction.

The secular variation at Hiyamizu is about 1/10 of that at Hakamagoshi, although in N76°E direction an inversion from contration to extention took place in Mar., 1959, and in N14°W direction an inversion from ex-

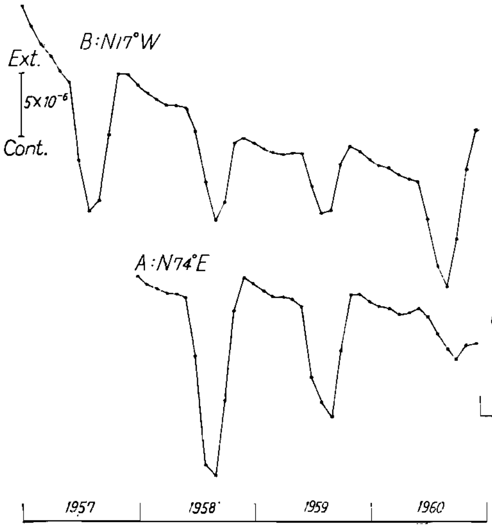


Fig. 9. (a) Monthly mean values of the extention and contraction at Hakamagoshi.

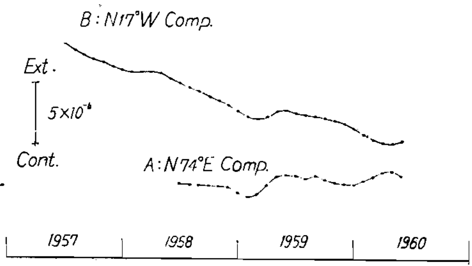


Fig. 9. (b) Secular variation of the extention and cantraction at Hakamagoshi.

Fig. 10. (a) monthly maan values of the extention and contraction at Hiyamizu.

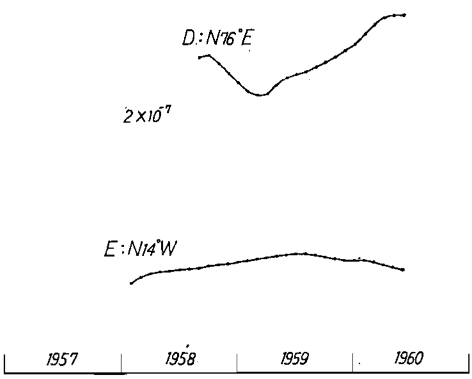


Fig. 10. (b) Secular variation of the extention and contraction at Hiyamazu.

tention to contraction in Aug., 1959.

Hereupon, let us adopt the model of the Volcano Sakurajima, as mentioned in part 1 of this series[2], and compare these secular variations with the deformation theoretically deduced from the model.

According to the model, the position of main pressure center was 10 km in depth under the center of the Aira caldera and the value of a^3P/μ increased with time. (P is the change of hydrostatic pressure in a small sphere with radius a, and μ is Lame's constant of the crust.)

The amounts of tilt and strain caused by crustal deformation expected from the model are given by the following equations, which are deduced from eq. (1) in part 1 of this series.

$$T=\left|\frac{\partial U_z}{\partial R}\right|_{z=-f}=\frac{3a^3P}{4\mu}\cdot\frac{-3fR}{(f^2+R^2)^{5/2}} \qquad (2-a)$$

$$E=\left|\frac{\partial U_R}{\partial R}\right|_{z=-f}=\frac{3a^3P}{4\mu}\cdot\frac{f^2-2R^2}{(f^2+R^2)^{5/2}} \qquad (2-b)$$

where f : depth of the pressure center from the ground surface,

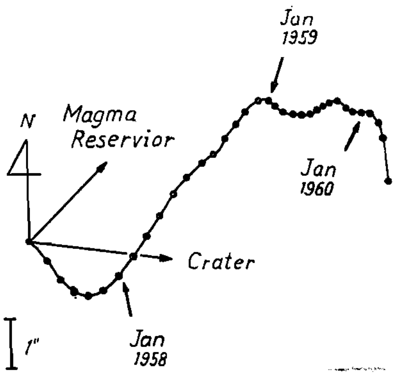


Fig. 11. Vectorical diagram of the secular variation at Hakamagoshi.

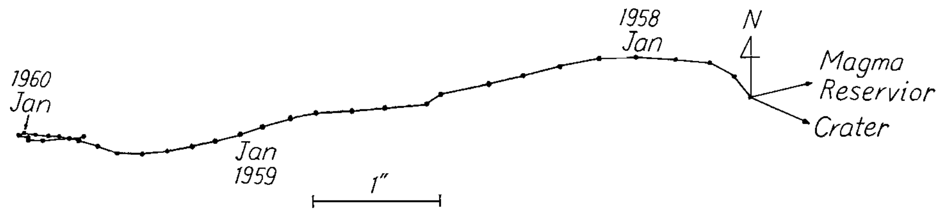


Fig. 12. Vectorical diagram of the secular variation at Hiyamizu.

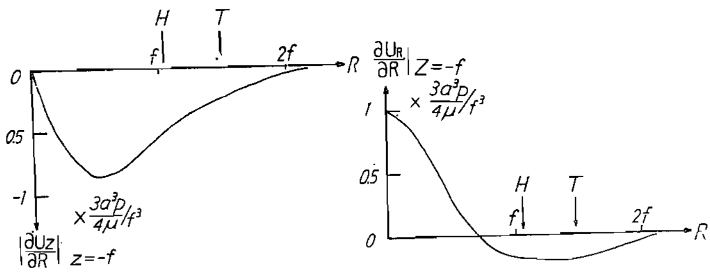


Fig. 13. Expected tilt and extention from the model.
H : Hakamagoshi T : Hiyamizu

R : horizontal distance from the pressure center to an observation station.

The relations between T or E and R are shown in Fig. 13. If $f=10$ km, the direction of tilt should show an upwards tilt to the pressure center, and the strain should be of contraction in the region of $R=7.1$ km.

The actual observed tilt variation at Hiyamizu is compatible with the expected one, but that at Hakamagoshi is not. The tilt variation at Hakamagoshi, having the opposite tendency to the expectation, may be regarded as originated from a particular movement of the active fault zone, as described in part 1 of this series. Such particular movement near the fault was also noted by Nishimura who pointed out the same movement in Beppu city[3].

Based upon the model deduced from the measurement by precise levelling, and using the observed values of tilt at Hiyamizu during Feb., 1958–Feb., 1960, it results in $f=10$ km, $R=13$ km, and $a^3P/\mu=7.1\times10^{13}$ cm^3, which, however, does not satisfy the strain obtained from extensometer at Hiyamizu. Now, if the values $f=19.1$ km and $a^3P/\mu=2\times10^{14}$ cm^3 are adopted, the result obtained from extensometer is compatible with that from tiltmeter. Which of both models is real, is not determined at present.

On the other hand, the value of $a^3P/\mu=5.9\times10^{14}$ is evaluated from the paper presented by Mogi who used the precise levelling data before and after the greatest eruption of this volcano in 1914[4].

Considering those results, some of the information on the state of magma reservior could be suggested from the routine observation by tilt-meter and extensometer, although the present observation is rather debatable for the precise estimation of the matter. Much information on the magma reservior could be obtained by setting many suitable observating stations. Recently as the first step of this purpose, two components of tiltmeters are set at Kirishma-chō, 23 km in NE direction apart from the pressure center.

7. Crustal deformation forerunning the volcanic eruption

The particular variation with the period of several days is often found in the record of tiltmeter at Hakamagoshi, as described in chapter 5. Some of these variations are associated with the volcanic eruption as marked by the arrow in Fig. 5, but many variations, occurring especially in winter season, are not likely to be related with the eruption, as pointed out by Minakami[5] who observed the tilt variation at the Volcano Asama[6].

To study the characteristic of abnormal deformation associated with the eruption, it is convenient to eliminate the harmonic deformation from the original records. Thus the overlapping mean of thirteen successive values at an interval of 2 hours are taken. That is, let $n_0, n_2, \cdots, n_{2p}, \cdots, n_{2p+12}$ be the values successively read at an interval of 2 hours on the record, then the overlapping mean becomes

$$N_{12}=\frac{n_0+n_2+\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots+n_{22}+n_{24}}{13}$$

$$N_{14}=\frac{n_2+n_4+\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots+n_{24}+n_{26}}{13}$$

and

$$N_{2p}=\frac{n_{2p-12}+n_{2p-10}+\cdots\cdots+n_{2p}+\cdots\cdots n_{2p+10}+n_{2p+12}}{13}.$$

The series of N thus obtained will represent the abnormal deformation associated with the eruption.

Some typical case will be picked up to be discussed.

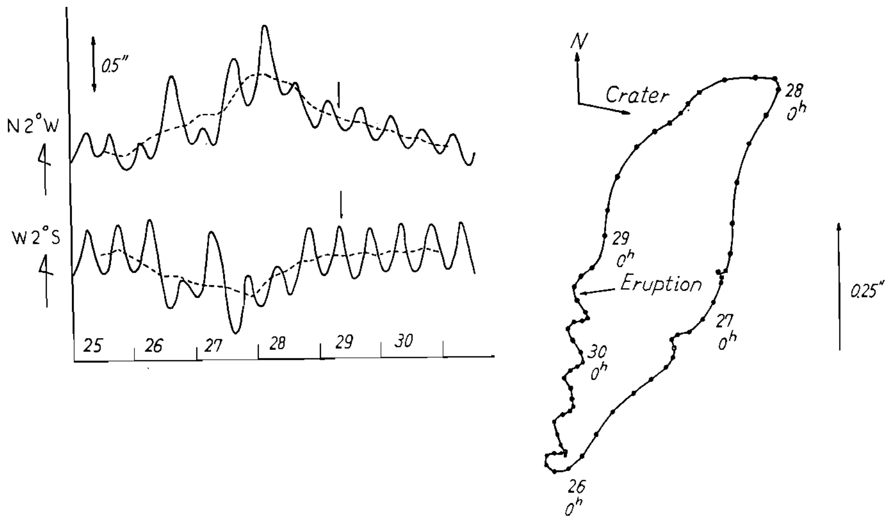


Fig. 14. Abnormal tilt at Hakamagoshi on the occasion of the eruption on 29 th of Mar., 1960.

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

Some of the records obtained on this occasion are shown in Photo. 2.

Analyzing the records at Hakamagoshi by the above method, the abnormal deformation is shown by broken line in Fig. 14 and Fig. 15. Fig. 14 also shows the vectorical diagram of abnormal tilt.

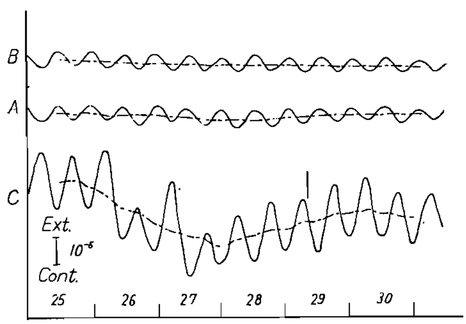


Fig. 15. Abnormal vertical contraction at Hakamagoshi on the occasion of the eruption on 29 th of Mar., 1960.

As seen from those figure, the tilt downwards NE direction began on 26 th, three days before the eruption, on 28 th its amount reached to about 0.75″ and then direction of tilt began to become opposite. The eruption took place on the way to return to the original position. On the other hand, the abnormal change is hardly recorded in horizontal components of extensometers, but in the vertical component the abnormal contraction corresponding to the tilt motion reached to the maximum strain of 2.5×10^{-6} as shown Fig. 15.

In the case of this eruption, the abnormal tilt was also recorded at Hiyamizu as shown in Fig. 16. The general feature of tilt is similar to

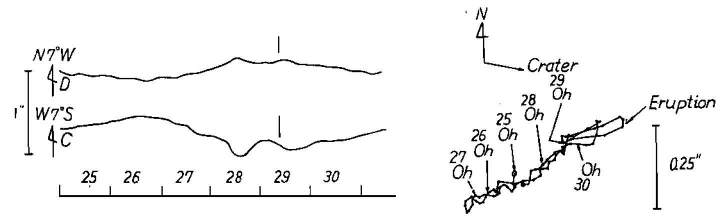


Fig. 16. Abnormal tilt at Hiyamizu on the occasion of the eruption on 29 th of Mar., 1961.

that of Hakamagoshi, that is, the tilt downwards NE direction occurred from three days before the eruption and then returned to the original position, but the similarity is not cospicuous, for example the feature of locus is different in each case and the tilt at Hiyamizu is smaller than at Hakamagoshi. The horizontal components of extensometer appear to exhibit nothing as well as that of Hakamagoshi, although one component of them is not available.

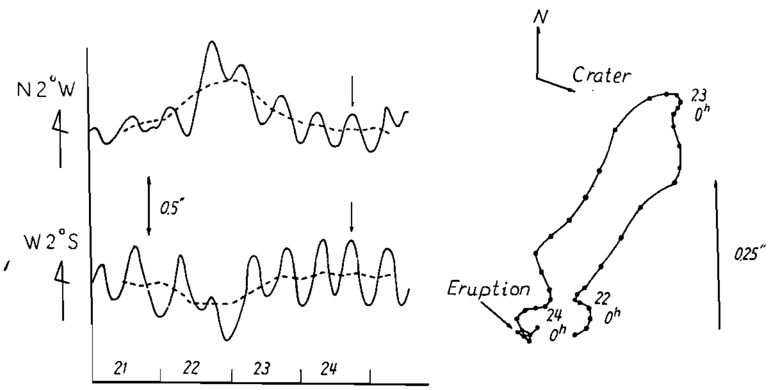


Fig. 17. Abnormal tilt at Hakamagoshi on the occasion of the eruption on 24 th of Feb., 1959.

In the case of the eruption on 24 th of Feb., 1959, the tilt downwards NE direction began on 22 nd, two days before the eruption, on 23 rd its amount reached to about 0.4″ and then the direction of tilt began to return to the original position. The eruption took place after returning completely to the original position (Fig. 17).

In the case of the eruption on 28 th of Dec., 1958, followed by the succeeding eruptions with uplift of new lava, a complicated movement which is different from the previous one was observed. Even in this case, the similar abnormal tilt downwards NE direction began on 26 th, two days before the eruption (Fig. 18).

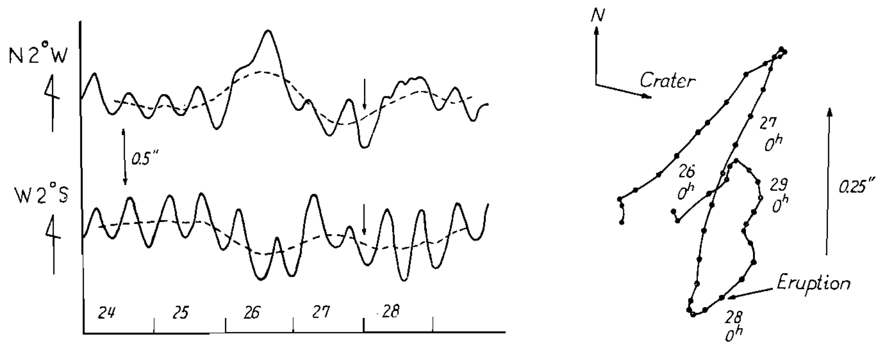


Fig. 18. Abnormal tilt at Hakamagoshi on the occasion of the eruption on 28 th of Dec., 1958.

From these examples, it is found that the tiltmeter at Hakamagoshi begin to record the abnormal tilt downwards NE direction several days before an eruption and the eruption takes place on the way of returning to the original position or after its return to the original position.

The occurrence of abnormal tilt towards the particular direction before the eruption, as above noted, may be considered as a clue for prediction of eruption. But the tilt direction is not different from that described by Sassa who pointed out an upward tilt to crater from observation of the crustal movement of the Volcano Aso[6] This is probably related with the interpretation that the main magma reservior of the Volcano Sakurajima is not situated beneath the crater, but northwards apart from the crater.

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 show an abnormal tilt downwards NE direction several days before the eruption.

8. Summary

In this paper, the result of routine observation by tiltmeter and extensometer at two stations are reported.

The results of this paper and the precise levelling reported in the previous paper are compared, and the relations with the eruption are discussed.

Summarizing the main results :

1) The variation of discharge of the volcanic energy with time during this active period increases with time. This fact coincides qualitatively with the result obtained in part 1, that is, the increase of the potential of the pressure center.

2) The harmonic variation of crustal deformation at Hakamagoshi is likely to be related with the fact that the permeation of sea-water varies owing to oceanic tide.

3) At Hakamagoshi located on the active fault zone, the direction of tilt in the active period of this volcano is opposite in the rest.

4) The observational results at Hakamagoshi are consists of the movement of Sakurajima as a whole and of the particular movement due to the active fault on which Hakamagoshi is situated, and the latter become sometimes so predominant that the former is unrecognazable. On the other hand, the observational results at Hiyamizu seems to be suitable to discuss the mechanism of crustal movement of the Volcano Sakurajima. Therefore, if we have many of such suitable observating stations as Hiyamizu, it would be possible to presume the state of magma reservior and find the mechanism of volcanic eruption.

5) A clue for the prediction of the volcanic eruption is obtained from the abnormal tilt in the difinite direction and abnormal contraction in vertical direction, which are usually observed several days before the eruption.

9. Acknowledgements

The auther wishes to express his cordinal thanks to Prof. Kenzo Sassa of Kyoto University for his kind guidance and encouragement throughout the study. He is greatly indebted to the kind helps shown by Mr. Shunzo Nakamura during the observation, and by Mrs. Syōko Tsuchiya and Miss Rei Kurashige during the arrangement of the data. He also expresses his thanks to Kagoshima Meteological Observatory for supplying him with the information on volcanic eruption.

Appendix

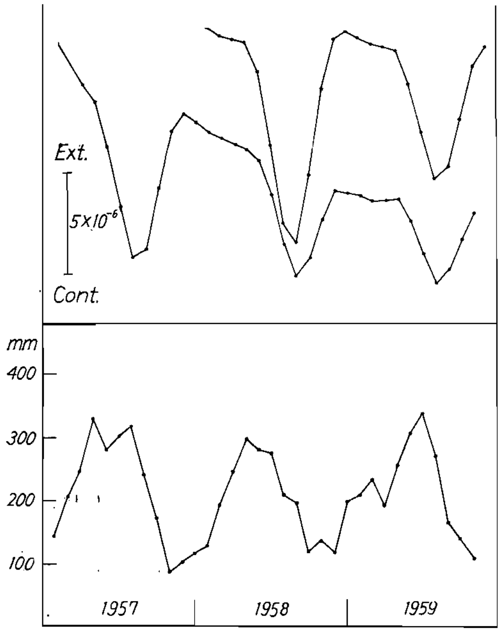


Fig. 19. Relation between the rain-fall and the extrodinal contraction at Hakamagoshi.

The extensometers at Hakamagoshi exhibits a great deal of variation in rainy season. Fig. 19 represents the overlapping means in three months of monthly amount of rainfall at Kagoshima city and of contraction (or extension) of land at Hakamagoshi, whose distance is about 4 km. from Kagoshima city. A close relation of both values is easily found in the Fig. 19, namely, the maximum strain of land deformation occurs 2–3 months later than period of the maximum rainfall.

References

1) "Rapid report of the volcanic eruption" issued by Kagoshima Meteological Observatory. No. 4.–No. 10 1955–1960.

2) K. Yoshikawa : "On the crustal Movement Accompanying with the Recent Activity of the Volcano Sakurajima (part 1)" Bull. Disaster Prevention Res. Inst., Kyoto Univ., No. 48, P. 1, 1956.

3) E. Nishimura : "On the earth tide (part 2)". CHIKYU-BUTSURI (Bull. Geophysical Inst., Facul. Sci., Kyoto Univ.,) Vol. 5, No. 1, 1941.

4) K. Mogi : "On the Relaticns Between the Eruptions of Sakurajima Volcano and

the Crustal Movements in its Neibourhood" Bull. Vol. Soc. Japan, Ser. 2, Vol. 1, No. 1, 1957.

5) T. Minakami : "On Volcanic Activities and Tilting of the Earth's Surface" Bull. Earthq. Res. Inst. Vol. 20, 1942.

6) K. Sassa : Micro-Seismometric Study on Eruptions of the Volcano Aso (part 2)". Mem. Coll. Sci., Kyoto Univ., Vol. 19, No. 1, 1936.

Nort on pate I.

In the section 2-3 of part I, the model on pressure origin is discussed by the mode of the relative vertical movement only in Sakurajima without the consideration of the uplift of Sakurajima as a whole. As seen from the table 2 of part I, however, the uplift of Sakurajima as a whole is estimated at 26.3 cm in the period from Mar. 1959 to Mar. 1960 (the precise levelling had been carried out in Mar. of each year). To take the total crustal movement into consideration, the previous results must be supplemented with the values evaluated in the case where the depth of the main pressure center is variable. It must be noted that the depth can be determined formally from the gradient alone which is deduced from the relative vertical displacement in Sakurajima, but the actually measured values are so scattered as to prevent us from determining an unique curve. In the case of 1957-1958, the values are not so scattered for us to find the depth of about 10 km without difficulty, but in the case of 1959-1960, the depth can not be determined so accurately, and the values shown in the following table are deduced, in which the depth is regarded as a parameter.

	I	II	III	IV	V
depth km	$\frac{3a^3P}{4\mu}\cdot 10^{13}$ cm^3	uplift of Hakamagoshi (calculated) cm	26.3-II cm	uplift of Kagoshima (calculated) cm	II-IV cm
5	0.18	0.5	25.8	0.3	0.2
10	0.57	1.7	24.6	1.2	0.5
15	1.66	3.9	22.4	3.1	0.7
20	4.00	6.7	19.6	5.9	0.7
25	7.04	8.6	17.7	7.8	0.8
30	12.5	11.5	14.8	10.6	0.9
40	34.5	19.4	6.9	18.5	0.9
45	57.8	26.2	0.1	25.3	0.9
50	90.9	33.7	7.4	32.8	0.9

On examining the table, we can conclude as follows :

1) In order to reconcil the applied model with the uplift of Hakamagoshi, the depth of the main pressure center must be about 45 km.

2) There is no case where both uplifts of Hakamagoshi and Kagoshima are simulteneously reconciled. That is, a discontinuous movement in the vertical direction between Sakurajima and Kagoshima must be taken into consideration.

3) The values of III of the table are regarded as the uplift of Sakurajima raised up by the other force than originated from the main pressure center. For example, it is not unreasonable that we put forward one model of pressure center, which is situated at any depth near the center of Sakurajima, because the distances between the pressure center and every benchmarks are nearly equal. The reality of the model should be first examined by carring out the precise levelling on the inner region of Sakurajima.

errata in part I

p. 9, line 3, for "$(a^3P/\mu)_B=1.06$ (at 1958-59)" read "$(a^3P/\mu)_B=1.06$ (at 1957-59)"

p. 9, line 4, for ,,$(a^3P/\mu)_B=1.07$ (at 1959-60)" read "$(a^3P/\mu)_B=0.07$ (at 1959-60)"

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 [illegible]. 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 Earth quake 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.

No.49 The Ground Motion Near Explosion by Soji Yoshikawa, 1961.

No.50 On the Crustal Movement Accompanying with the Recent Activity of the Volcano Sakurajima (Part 2) by Keizo Yoshikawa, 1961.

Bulletin No. 50 Published February, 1962

昭和 37 年 2 月 15 日 印刷
昭和 37 年 2 月 20 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