19. Changes in the Heights of Volcano Asama caused by Eruptions in 1935.

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1. Introduction.

Geophysicists and geologists have pointed out certain characteristic topographies near volcanoes from various points of view, especially on the fact that the presence of a number of lakes or regions of depression on the skirts of a volcano is due to topographic deformations that follow volcanic activities whether in recent or in geological times.

The results moreover of precise levellings and triangulations that were carried out around some volcanoes both before and after activities, helped to make clear the depressions and elevations of the ground, particularly those in the large provinces. At the time of the explosions of Sakura-zima[1] in 1914, the meaning of a depression of 2 m in the vicinity of the volcano and of those of several centimetres even at a distance of 100 km from it, became clear not only from precise levellings but from triangulations as well as. In the explosions of volcano Usu[2] in 1910, on the other hand, an upheaval of the volcano was reported. In the case of the eruption of Komagadaké[3] in Hokkaidô in 1929, the depression of elliptic form resembled what happened in the case of the eruptions of Sakura-zima above described, but the former deformations were on a smaller scale compared with the latter ones.

From triangulations carried out by the Land Survey Department, the height of the central cone of volcano Asama was determined as being 2542 m above sea level. In 1935, in the midst of volcanic activities, precise levellings were executed by experts of Land Survey Department. The present line of levels runs along the southern foot, the east and west-south slopes of the volcano and the southern margin of the crater. From the results of these surveys, it was found that the

1) F. ÔMORI, *Bull. Imp. Earthq. Inv. Comm.*, **8** (1914~1922), 158.
2) F. ÔMORI, *Bull. Imp. Earthq. Inv. Comm.*, **5** (1911), 101.
3) C. TSUBOI, *Bull. Earthq. Res. Inst.*, **8** (1930), 298.
J. UEDA, "Reports on the Eruption of Komagadaké", (1932), (in Japanese).

volcano increased about 18 m in height during an interval of 23 years. Dr. R. Takahasi[4] has reported in detail the results of present precise levellings in the same bulletin.

2. Observations of Zenith Distance at Asama in 1934 and 1935.

Most of the studies concerned with topographic deformations accompanied with volcanic activities, were made from comparisons of these surveys that were made a number of years before and after the volcanic activities. Consequently, the topographic deformations determined from the results of these surveys usually include chronic changes, so that they cannot be regarded as having been produced suddenly on the occasion of an eruption. Besides, we have not as a rule the means of distinguishing the chronic changes from the obtained results. Thus, in order to ascertain the topographic deformation directly due to the volcanic activities, free from chronic changes, the writer at Asama has

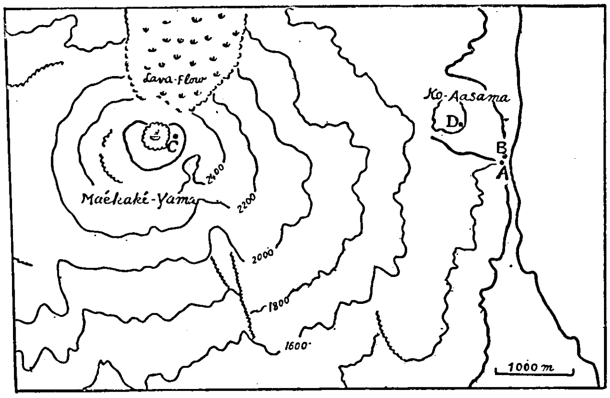

Fig. 1. Topographic map of volcano Asama and its vicinity.

successively carried out trigonometric levellings; that is, the observation of zenith distance, during the calm period of the volcano in 1934 and it's active period in 1935. For triangulation point (C) on the central cone, the writer utilized the upper edge of a large volcanic bomb, "Taisio-Iwa", which is 3·5 m in diameter and at a distance of about 20 m east from the margin of the crater (Fig. 1). For point (D), he adopted the top of the parasitic volcano, "Ko-Asama", which is about 1 km N-W from our observatory. The later triangulation point is a concrete pile 1·5 m in length. Thus, from a fixed stand (B) in our observatory, the observations of zenith distance were collimated with

4) R. TAKAHASI, *Bull. Earthq. Res. Inst.*, **14** (1936), 18~25.

Wild's theodolite for the two triangulation points above described. The observation which was begun July, 1934, is being continued (1936). Naturally, in cloudy weather, or when there is huge emission of vapour from the crater, it is impossible to carry out these measurements.

In the following Table I (a) (b), are given the complementary angles of zenith distance between triangulation point C and observation-stand B, during 1934 and 1935.

Table I. (a)

date	θ	$\Delta\theta$	date	θ	$\Delta\theta$
1934 h	15° 28′ ″	″	1934 h	15° 23′ ″	″
July 9, 12·8	37·2	+ 9·7	Aug. 19, 14·5	20·2	− 6·3
〃 19, 13·5	28·0	+ 1·5	〃 20, 11·0	21·2	− 5·3
Aug. 3, 6·0	33·8	+ 7·3	Sept. 11, 15·0	12·6	−12·9
〃 〃 16·0	23.8	− 2·7	〃 12, 11·5	23·1	− 3·4
〃 4, 10·0	22·8	− 3·7	〃 〃 13·5	38·7	+12·2
〃 〃 11·0	27·0	+ 0.5	Oct. 14, 10·0	15·6	− 9·9
〃 5, 16·7	12·2	−14·3	〃 20, 15·0	34·2	+ 7·7
〃 6, 11·0	23·2	− 3·3	〃 〃 13·0	28·8	+ 2·3
〃 〃 13 0	27·0	+ 0.5	〃 30, 14·4	20·2	− 6·3
〃 〃 14·0	39·8	+13·3	Nov. 13, 12·0	30·8	+ 4·3
〃 〃 15.0	36·2	+ 9·7			

Mean $\theta = 15° 28' 26{\cdot}5'' \pm 5.4''$

Table I. (b)

date	θ'	$\Delta\theta'$	date	θ'	$\Delta\theta'$
1935 h	15° 28′ ″	″	1935 h	15° 28′ ″	″
April. 21, 14·0	8·0	− 0·5	May 17, 14·0	7·9	− 0·6
〃 24, 11·5	4·8	− 3·7	〃 24, 13·0	15·0	+ 6·5
May 9, 10·0	3·0	− 5·5	〃 30, 12·0	7·0	− 1·5
〃 〃 14·0	14·0	+ 5·5	July 29, 14·0	7·9	− 0·6

Mean $\theta' = 15° 28' 8{\cdot}5'' \pm 2{\cdot}8''$

In Table I (a) (b), θ, θ' are average values of three direct and reverse measurements by Wild's theodolite, while $\Delta\theta$, $\Delta\theta'$ are residues for each observed value. Naturally, θ, θ' must involve errors due to the daily and seasonal refractions. Upon reviewing the residues, it will be found that those observed before 10 h and after 14 h are unusually large compared with the others. They will be regarded mostly as errors due to abnormal refraction and to errors of observation due to difficulties of collimating with exactitude. Consequently, in the following discussion, observations carried out before 10 h and after 14 h will be excluded.

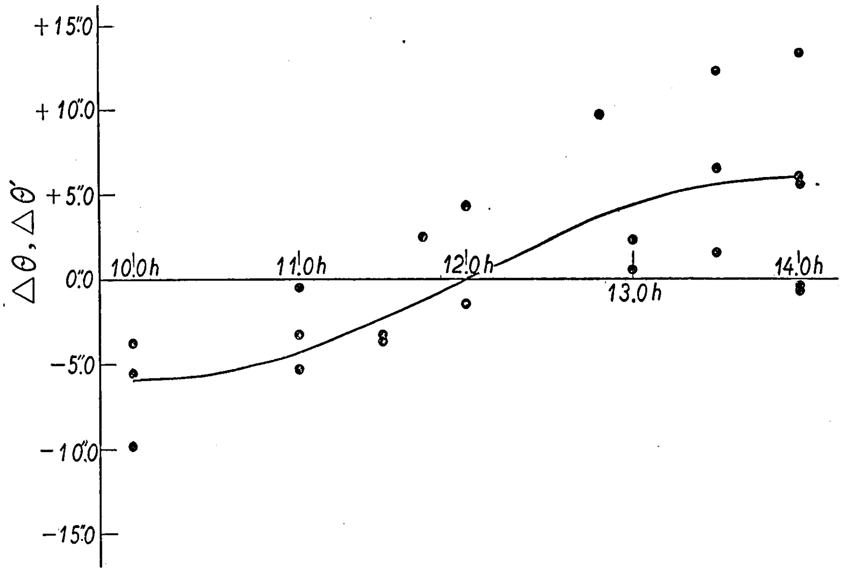

Fig. 2.

In Fig. 2, $\Delta\theta$, $\Delta\theta'$ are plotted as abscissa in taking the time in which the observations were executed. A glance at this Fig. 2, shows these residues $\Delta\theta$, $\Delta\theta'$ to be evidently systematic with respect to the time these observations were carried out. Though they somewhat fluctuate, roughly speaking, these residues observed from 10 h to 12 h are generally negative, while in contrast to them, those observed from 12 h to 14 h are generally positive. In addition, they vary somewhat linealy or in sine form with the time of observations. In consideration of the tendency illustrated in Fig. 2, we shall assume that these residues connected with observation-time are due to the daily refraction, which varies with sine form. On the other hand, it will be not far from the fact that other refractions, seasonal and annual, are considered approximately constant. For convenience, we shall consider the total refraction α to be composed of the daily one α_1 and the seasonal one α_2.

$$\alpha=\alpha_1+\alpha_2\,, \tag{1}$$

$$\alpha_1=k\sin\frac{2\pi}{4}(h-12)\,, \tag{2}$$

$$\alpha_2=\text{const.}. \tag{3}$$

Thus, by means of the method of least-squares, k in (2) is determined as 6·0″. As results, the observed values θ, θ' are corrected for daily refraction. In Table II, (a) (b) are given the corrected values for the daily refraction.

Table II. (a)

date	$\theta+\alpha_1$	$\Delta(\theta+\alpha_1)$	date	$\theta+\alpha_1$	$\Delta(\theta+\alpha_1)$
1934	15° 28′		1934	15° 28′	
July 9, 12·8h	34·0″	+ 4·9″	Aug. 20, 11·0h	26·9″	− 2·2″
〃 〃 13·5	24·0	− 5·1	Sept. 12, 11·5	27·0	− 2·1
Aug. 4, 10·0	29·8	+ 0·7	〃 〃 13·5	34·3	+ 5·2
〃 〃 11·0	32·3	+ 3·2	Oct. 14, 10·0	24·3	− 4·8
〃 6, 11·0	28·4	− 0·7	〃 20, 13·0	26·0	− 3·1
〃 〃 13·0	24·3	− 4·8	Nov. 13, 12·0	32·1	+ 3·0
〃 6, 14·0	34·6	+ 5·5			

Mean $\theta+\alpha_1=15° \; 28' \; 29{\cdot}1'' \pm 2{\cdot}7''$

Table II. (b)

date	$\theta'+\alpha'_1$	$\Delta(\theta'+\alpha'_1)$	date	$\theta'+\alpha'_1$	$\Delta(\theta'+\alpha'_1)$
1935	15° 28′		1935	15° 28′	
April 21, 14·0h	2·0″	− 3·7″	May 17, 14·0	1·9″	− 3·8″
〃 24, 11·5	7·1	+ 1·4	〃 24, 13·0	11·0	+ 5·3
May 9, 10·0	7·0	+ 1·3	〃 30, 12·0	7·0	+ 1·3
〃 〃 14·0	8·0	+ 2·3	July 29, 14·0	1·9	− 3·8

Mean $\theta'+\alpha'_1=15° \; 28' \; 5{\cdot}7'' \pm 2{\cdot}2''$

At the same time, the observations for a triangulation point D on the parasitic cone "Ko-Asama" were carried out by the same method. In the following Table III (a) (b), the complementary angles of zenith distance φ, φ' in 1934 and 1935 are given with the date and time for observation executed. In the same Table, $\Delta\varphi$, $\Delta\varphi'$, $\Delta\varphi_s$, $\Delta\varphi'_s$ are residues from the average value of total observations and of selected observations carried out from 10 h to 14 h.

As will be seen from Table III, there do not appear any conspicuos changes of zenith distance for "Ko-Asama" caused by the present activities.

On the other hand, in the zenith distance for the triangulation point C, a remarkable change was produced at the interval between December, 1934, and April, 1935. While, as has already been reported in the previous paper, the violent explosion occurred on April 20, 1935,

Table III. (a)

date			φ	$\Delta\varphi$	$\Delta\varphi_s$
1934		h	16° 50′		
July	28,	10·5	37·6″	− 7·7″	− 8·8″
Aug.	1,	14·0	42·1	− 3·2	− 4·3
〃	2,	8·0	37·0	− 8·0	
〃	3,	16·3	31·4	−13·9	
〃	4,	10·0	48·4	+ 3·1	+ 2·0
〃	〃	11·0	44·6	− 0·7	− 1·8
〃	6,	11·0	45·0	− 0·3	− 1·4
〃	〃	13·0	40·8	− 4·5	− 5·6
〃	〃	15·0	57·0	+11·7	
〃	9,	10·0	46·8	+ 1·5	+ 0·4
〃	12,	8·0	57·2	+11·9	
〃	〃	11·0	54·6	+ 9·3	+ 8·2
〃	13,	14·0	49·2	+ 3·9	+ 2·8
〃	14,	16·0	41·2	− 4·1	
〃	19,	14·0	40·8	− 4·5	− 5·6
〃	20,	11·0	45·2	− 0·1	− 1·2
Sept.	12,	8·0	32·4	−12·9	
〃	〃	13·5	49·6	+ 4·3	+ 3·2
〃	〃	16·5	33·8	−11·5	
〃	27,	10·5	42·2	− 3·1	− 4·2
Oct.	14,	10·0	55·8	+10·5	+ 9·4
〃	20,	10·0	54·2	+ 8·9	+ 7·8
〃	13,	12·0	55·0	+ 9·7	+ 8·6

Mean $\varphi = 16° \ 50' \ 45{\cdot}3''$
Mean $\varphi_s = 16° \ 50' \ 46{\cdot}4'' \pm 3{\cdot}9''$

Table III. (b)

date			φ'	$\Delta\varphi'$	$\Delta\varphi'_s$
1935		h	16° 50′		
April	21,	15·6	36·0″	− 7·3″	
〃	24.	10·5	49·0	+ 5·7	+ 3·2″
May	4,	10·0	49·6	+ 6·3	+ 3·8
〃	9,	10·0	45·5	− 2·3	− 0·2
〃	17,	13·0	42·0	− 1·3	− 3·8
〃	24,	12·6	42·6	− 0·7	− 3·2
〃	30,	16·0	38·6	− 4·7	

Mean $\varphi' = 16° \ 50' \ 43{\cdot}3''$
Mean $\varphi'_s = 16° \ 50' \ 45{\cdot}8'' \pm 2{\cdot}4''$

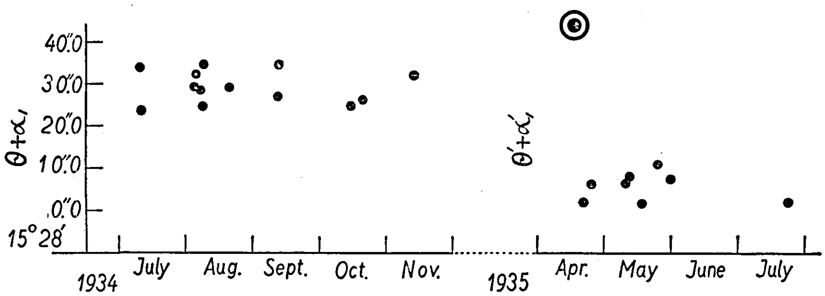

Fig. 3.

⊙; The explosion on April 20, 1935.

$\theta+\alpha_1=15°\ 28'\ 29{\cdot}1''\pm2{\cdot}7''$; mean value of complementary angle (B-C) of zenith distance before explosion.

$\theta'+\alpha'_1=15°\ 28'\ 5{\cdot}7''\pm2{\cdot}2''$; the one after explosion.

$\varphi_s=16°\ 50'\ 46{\cdot}4''\pm3{\cdot}9''$; mean value of complementary angle (B-D) of zenith distance before explosion.

$\varphi'_s=16°\ 50'\ 45{\cdot}8''\pm2{\cdot}4''$; the one after explosion.

$(\theta'+\alpha'_1)-(\theta+\alpha_1)=-23{\cdot}4''\pm3{\cdot}5''$; change caused by explosion.

As the result, the changes of zenith distance for the triangulation point C were observed, which were accompanied directly with the present volcanic activities.

3. Distance between the Triangulation Point on central Cone and the fixed Point at our Observatory

If the distance between these two points — the one C on the central cone and the other B at our observatory — is known, it will give the variation in the zenith distance as the unit of length.

For the present purpose, we can utilize the results of precise levellings carried out in 1935. That is, the height of two bench-marks from the geoid, one on the central cone which coincides with triangulation point C above described, the other A at our observatory which differs from the fixed point B. First, in order to know the distance between B and C, we will determin the distance between two bench-marks A and C.

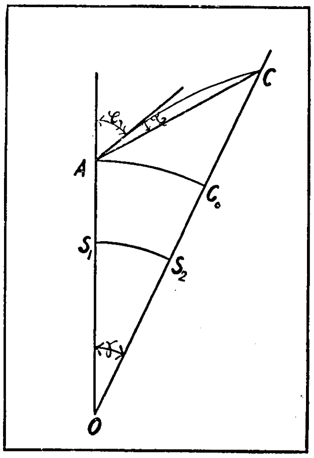

Fig. 4.

From a triangle ACC_0 in Fig. 4, we can obtain the following formula:

$$AC_0=(h_2-h_1-H)\frac{\sin\left[\zeta-\left(\frac{1}{2}m\right)\gamma\right]}{\cos\left[\zeta-(1-m)\gamma\right]},$$

AS_1O, CS_2O; normals on the geoide S_1S_2,

$<AOC=\gamma$

$AS_1=h_1=1405{\cdot}820$ m,

$CS_2=h_2=2557{\cdot}993$ m,

$H=1{\cdot}633$ m; height from the bench-mark A to the telescope of theodolite,

$m=\frac{\alpha_2}{\gamma}=0{\cdot}06564$; m refraction coefficient,

$\delta=\frac{\pi}{2}-\zeta$.

Table IV.

$\zeta=\frac{1}{2}(\pi\pm\delta)$		δ
97° 41′ 37·2″	weighted mean 97° 41′ 36·7″	15° 28′ 25·7″
〃 〃 34·5″		
〃 〃 36·8″		
82° 13′ 14·5″	82° 13′ 11·0″	
〃 〃 11·0″		
〃 〃 9·4″		

As the result, we obtain the horizontal distance between A and C,

$$AC_0=\overline{AC}=4146{\cdot}600 \text{ m}.$$

Thus, we can obtain the horizontal distance between B and C by making use of the above result. In Fig. 5, angle B is very small, so that the horizontal distance B-C is given by a simple correction to the horizontal distance A-C.

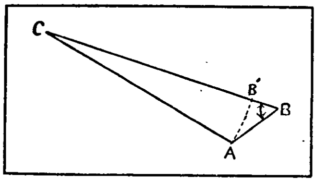

Fig. 5.

$$BC=BB'+B'C=AC+AB\tan B$$
$$=4151{\cdot}397 \text{ m},$$

where $AB=29{\cdot}475$ m,

$<B=80°\ 38'\ 18''$.

Thus finally, the horizontal distance between two points B and C is determined.

Here, we will return to the problem of topographical deformation in the present volcanic activities. According to Fig. 6 the difference of height between the triangulation point C and the fixed point B is indicated in the following:

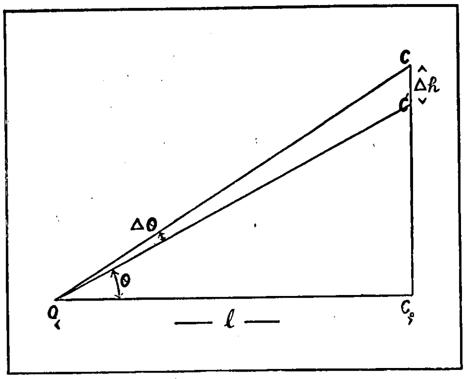

Fig. 6.

$C\,C_0 = h = l \tan(\theta + \alpha_1 + \alpha_2) + H$; height before explosion.
$C'C_0 = h' = l' \tan(\theta' + \alpha_1' + \alpha_2') + H'$; height after explosion.

We can put

$l = l' = 4151{\cdot}397$ m ; horizontal distance B–C,
$\alpha_1 = \alpha_1'$; angle caused by daily refraction,
$\alpha_2 = \alpha_2'$; angle caused by seasonal and other refractions,
$H = H'$; height of telescope of theodolite.

If we denote

$$\theta' - \theta = \Delta\theta = -23{\cdot}4'' \pm 3{\cdot}5'',$$
$$h' - h = \Delta h$$

as the topographical change, we get

$$\Delta h = l.\Delta\theta.\frac{1}{\cos^2(\theta + \alpha_1 + \alpha_2)} = -50{\cdot}7 \text{ cm} \pm 7{\cdot}5 \text{ cm}.$$

The amount of topographical change determined by this method is sufficiently independent of the error due to the refraction of light, though it has sensible effects in the case of determination of absolute height by triangulation.

At all events, the relative subsidence of the central cone which is about 50 cm, appeared before or soon after the violent explosion of April 20, 1935. While the relative change to the parasitic volcano "Ko-Asama" was not observed through the present volcanic activity.

4. Discussion of the Result.

Regarding the occurrence of topographical deformation in the present activities, it may be possible to explain it from various points of view.

For instance, decrease of vapour pressure owing to the explosion may produce depression in the central cone and in the vicinity of crater.

Besides, large ejection of lava as volcanic bombs and volcanic ash from the crater at the occasion of an explosion, may cause depression of ground near the crater.

On the other hand, from the observations of volcano Kilauea and Mauna Loa, in Hawaii, T. A. Jagger[5] reported that the elevations and depressions in the vicinity of these volcanoes clarified by the precise levellings coincided with the direction of tilting observed by the horizontal pendulums. However, from the observations of tilting of ground by a pair of Ishimoto's clinograph in our observatory, as discussed in the previous paper,[6] tilting in the direction of crater lasted from April 13 to May 1, 1935 and amounted to about 10″. It means, therefore, that the direction of tilting coincided with the region of depression. Moreover, if tilting of ground between the central cone and our observatory be the same amount as the one observed at our observatory, about half the amount of depression of central cone will be explained by this tilting motion.

On the other hand, as an explanation of the depression of ground accompanied by the violent explosion of Sakura-zima, 1914, Dr. N. Miyabe[7] remarked that the huge accumulations of lava ejected in the circumference of volcano would produce an elastic deformation of the crust. Naturally, in the present case of Asama, the elastic deformation caused by load of ejecta may be possible, but increase of ejecta accumulated on the central cone in many eruptions did not coincide with that of depression. In consequence, it will be more plausible that, instead of load deformation, the elevation which had been produced before the explosion, recovered by the decrease of vapour pressure after the violent explosion on April 20, 1935.

Thus, there seems to be various alternative explanations to account for this phenomenon. It will be premature to propcse any definite conclusion on this point, unless other evidences on this question come to light.

5. Relative Changes in Height of central Cone in Comparison with Maékaké-yama.

In his previous paper[8], the writer reported the amount of ejecta

5) T. A. JAGGER and R. H. FINCH, *Bull. Seis. Soc. Amer.*, **19** (1929), 38.
6) T. MINAKAMI, *Bull. Earthq. Res. Inst.*, **13** (1935), 629.
7) N. MIYABE, *Bull. Earthq. Res. Inst.*, **12** (1934), 471.
8) T. MINAKAMI, *Bull. Earthq. Res. Inst.*, **13** (1935), 790.

accumulated on the central cone on May 31, 1935. As the result of frequent explosions since that day, the ejecta accumulated near the crater gradually increased its amount. According to the investigation of the depth of ejecta on October 23 of the same year, it amounted to about 3 m in maximum depth. In Fig. 7, the depth of ejecta measured along the east direction on an central cone from the crater edge is illustrated with the date of absevation.

In Fig. 7, C represents the large bomb of 3·5 m in diameter, which was used as the triangulation point in the observation of zenith distance. As the result, the large bomb C shows only its edge of about 0·4 m in the later part of November, 1935, through accumulation of ejecta.

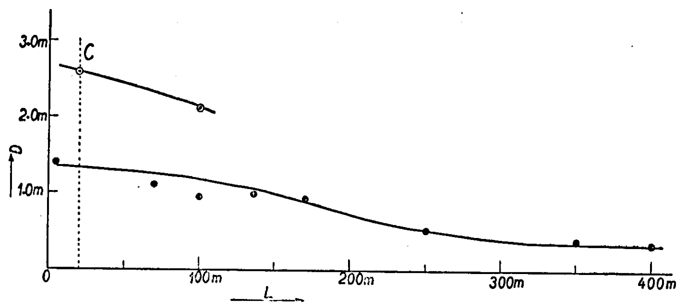

Fig. 7. Depth of ejecta accumulated on the central cone.
●; measurement on 31 May, 1935.
◉; measurement on 23 October, 1935.

On the other hand, the writer sometimes carried out observations of the relative height of two points, one the highest point on the central cone, the other on Maékaké-yama (ancient central cone). The survey was applied to the triangulation in taking the base line of 40 m on the central cone. Because of destruction of triangulation points on the central cone, it is impossible strictly to make clear the topographic changes which would be produced before and after the present volcanic activities. But, by determing the new triangulation point which approximately agrees with the old one, the writer carried out the survey after the explosion. The values obtained are given in Table V, with the date on which they were observed.

As will be seen in Table V, the height of the central cone relating to Maékaké-yama increased by 1·0 m on May 31 and 2·5 m on October 23, 1935 in comparison with the one of October, 1934. These changes of height correspond to the accumulation of ejecta. At any rate, the central cone increased its height by 2 m in comparison with the one before the present volcanic activity, though the central cone itself depressed by 50 cm as described in the foregoing page.

Table V.

date	θ	$h = l \tan \theta$	Δh
Sept. 7, 1935	2° 31′ 28·0″	31·20 m	
〃 28, 〃	2° 31′ 38·0″	31·26 〃	+0·06 m
Oct. 13, 〃	2° 31′ 9·6″	31·22 〃	−0·04 〃
〃 26, 〃	2° 31′ 46·2″	31·30 〃	+0·08 〃
May 31, 19 6	2° 39′ 46·0″	32·05 〃	+1·05 〃
Oct. 23, 〃	2° 44′ 41·0″	33·50 〃	+1·45 〃

$l = 722{\cdot}19$ m,
l; horizontal distance between two points.

In consideration of these facts, it may be plausible that the elevation of about 18 m which was made clear by the precise levellings carried out in 1935, is explained by the accumulation of ejecta, and that the volcano itself sometimes elevates and sometimes depresses within smaller ranges with the volcanic activities.

6. Résumé.

The writer carried out the triangulation in order to make clear the topographic deformation of volcano Asama. The observations have been continued since July, 1934, while, the volcano frequently repeated its explosive eruptions since April 20, 1935. From the result of triangulation, a depression of 50 cm of the central cone was observed through the present activities. Explanation of the present depression is possible from various stand-points, for instance, tilting of ground, deformation caused by decrease of vapour pressure.

On the other hand, the accumulation of ejecta amounted to 3 m in depth on the central cone, which was measured on October 23, 1935. After all, volcano Asama increased its height by about 2·5 m after the explosions of 1935, in spite of the depression of the central cone itself.

In conclusion, the writer wishes to express his thanks to Professor Mishio Ishimoto and Doctor Ryûtarô Takahasi for their interest, and encouragements given to the writer in the course of this research.

19. 最近の活動に伴へる淺間火山の高さの變化

地震研究所 水 上 武

I. 大正3年の櫻島大噴火並に昭和4年の北海道駒ケ嶽の活動に伴ひ，同火山近傍に著しい土地の沈降が現れた．又明治43年の有珠火山の活動には土地の隆起が伴つた事が報告されて居る．然し，是等の地形變動は，火山活動の數年前或は數十年前の水準測量又は三角測量と火山活動後に施行された測量との比較から求められた變化である．從つて直接火山活動に伴つたものと慢性的のものとを含むものである．

II. 筆者は淺間火山に關して，火山活動に直接隨伴する地形變動を明かにするため，昭和9年7月より天頂角の測定を繼續して行つた．

その結果昭和9年7月より11月迄の中央火口丘の高さに比し，昭和10年4月20日の爆發後に於いては約50糎の相對的沈降が觀測された．この沈降に對しては種々の解釋が出來るが觀測點が少いので，今回の活動に伴つた同火山の地形變動の全般に亘つて論ずる事は，やゝ危險の樣に思はれる．從つて，こゝでは相對的沈下の事實の指摘に止める事にした．

III. 昭和10年4月以來の數十回の噴火の爲に中央火口丘上に堆積する噴出物は極めて多量に達し，同年10月23日の測定に依ると，厚さ3米に達する處がある．從つて50糎の相對的沈降は山體自身の沈下に依るとしても，淺間山の高さは，噴火前に比して2米以上も增した事になる．

今回の噴出物の堆積狀態を考慮すると，大正6年と昭和10年の測量の比較から判明した18米の淺間山の高さの增加は，噴火に伴つて噴出した火山彈，火山灰の堆積が主要な原因の樣に思はれる．