11. Precise Leveling at the Eastern Foot of Volcano Usu.

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1. Introduction.

The eruption of Mt. Usu in Hokkaido which began in July 1910[1] resulted in the formation of 45 new craters on the northern plains of the volcano. After that it stopped activity and lay dormant for many years. Then, on Dec. 27, 1943, the inhabitants at the foot of Mt. Usu were frightened at the occurrence of a large number of earthquakes. The frequency of felt earthquakes increased day by day, until at last on Jan. 4 of the next year more than 300 earthquakes were felt in one whole day at the northwestern foot of the mountain, and it was feared that might be heralding an eruption. The seismic activities in these regions decreased quickly in February, but by this time it became clear that, in the wake of very shallow earthquakes, a remarkable crustal deformation, namely the elevation movement of land, was proceeding on the eastern plains of the mountain. There ran from north to south across this elevating area a road, a water drain for irrigation, a railway line and the River Osaru, and these were all cut at many points as the result of the rising of ground that had now taken place. The present author[2] visited the scene of disturbance with Dr. T. Minakami[3] in March 1944 to make precise measurements, and also conducted the second and third surveys in April and July of the same year.

2. The Precise Leveling.

In the first investigation made at the end of March, seven temporary bench marks were placed along the road traversing the elevating area as seen in the map (Fig. 1). In the second investigation resurveys were carried

1) F. OMORI, *Bull. Earthq. Inv. Comm.*, 5 (1911), 1.

2) S. OMOTE, *Spec. Bull. Earthq. Res. Inst.*, 3 (1944), 23.

3) T. MINAKAMI, *Spec. Bull. Earthq. Res. Inst.*, 3 (1944), 1. *Bull. Earthq. Res. Inst.*, 25 (1947), 65, 71; 27 (1949), 123, 129.

out with these bench marks to find the amounts of their upheaval during the interval of a month. From the result represented by curve A in Fig. 2, we know that BM-5 had elevated more than 5 meters within a month. The upheaval movement of this area was so conspicuous that the daily changes in the altitude of these bench marks could be measured. The amounts of upheaval of the bench marks within a whole day, from April 17th to 18th and from 18th to 19th, are given in Fig. 3-A. In this figure the movement at BM-5 is found to have been the most active, the upheaval velocity amounting to 30 cm. per day. Dividing the amount of upheaval of each bench mark during the period between the first and the second surveys by the number of days in the same period, we get the average daily amount of upheaval during that period. The average daily changes in the respective bench marks are shown in Fig. 3-B. This curve closely resembles the curves in Fig. 3-A, which show the actual daily changes in the altitude of the bench marks. The similarity of these two groups of curves in Fig. 3

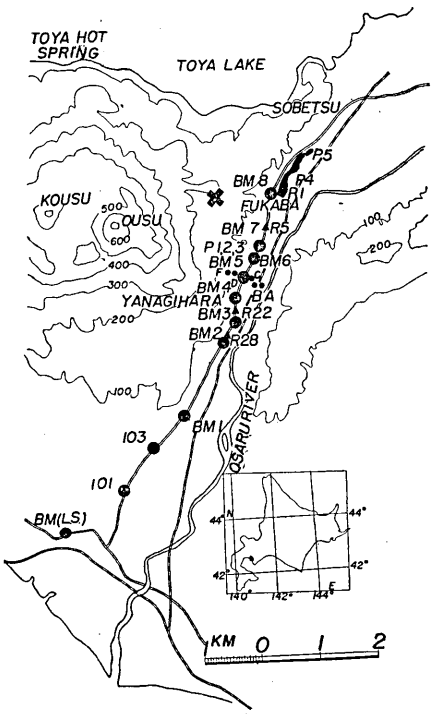


Fig. 1.
BM; Bench marks placed by the author.
R; Bench marks placed by the Public Works of the Hokkaido Office.
P; Pond.
×; New crater.

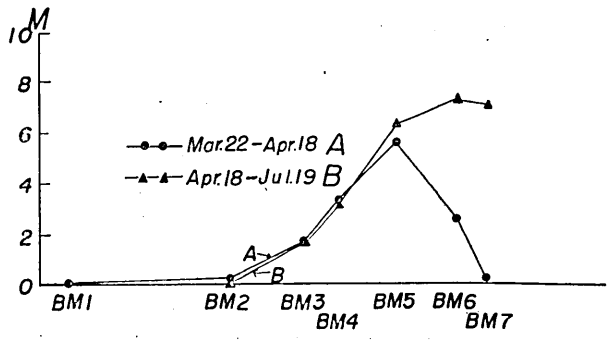


Fig. 2. Changes in the altitude difference of bench marks.

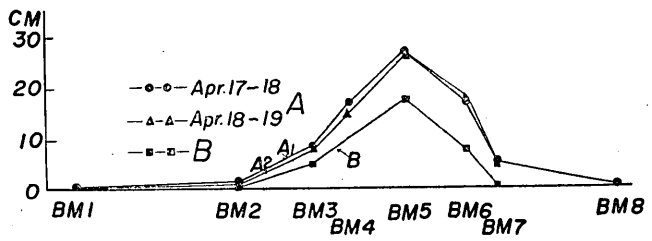


Fig. 3. Changes in the altitude difference of bench marks.
A; Changes within a whole day.
B; Averaged amount of change per day.

may indicate that the upheaval had continued with an almost constant velocity day by day from March to April, which is a very remarkable fact concerning the mechanism of the upheaval phenomena.

The third leveling survey was carried out in July after the explosions had begun at the newly formed crater. Changes in the altitude of bench marks during the three months that had elapsed after April are shown in Fig. 2-B. In this case too, as in the second survey, the amount of upheaval of each bench mark during the whole day from July 16th to 17th has been measured. The result is to be seen in a curve in Fig. 4-A. Also, as we did in the second survey, we calculated from Fig. 2-B the average daily change in the altitude of each bench mark during the period from April to July. The result is shown by a curve in Fig. 4-B. If we compare these two curves, A and B in Fig. 4,

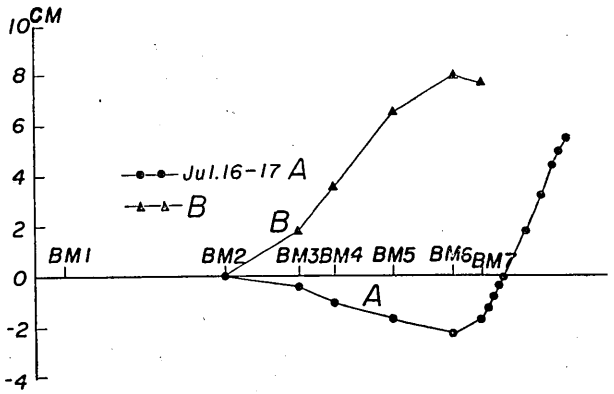


Fig. 4. Changes in the altitude difference of bench marks.
A; Changes within a whole day.
B; Averaged amount of change per day.

we at once notice that, unlike the curves in A and B of Fig. 3, these two curves in Fig. 4 differ considerably from each other in appearance. This tells us that in July a mode of upheaval movement different from that in March and April was going on. In April the upheaval velocity at BM-5 was the largest, but in July it became very small, and in its stead BM-7 came to show the most active movement.

From these curves, however, we cannot tell the time when the rising of BM-5 became less active and that of BM-7 became conspicuous.

Fortunately, at the end of April temporary bench marks of wooden piles were set up by the Bureau of Public Works of the Hokkaido Office along the same road along which our bench marks, BM-1 to 7, had been installed. The geographic distribution of these pile marks will be seen in the map of Fig. 1. It will be observed that some of the pile marks were installed very near to the author's bench marks. After April levelings were repeatedly carried out with these pile marks. The curves in Fig. 5 show the altitude of the respective bench marks at different times. From these curves we may infer the mode of the velocity change in the upheaval movement of each pile mark throughout the whole period from April to July. To facilitate comparison the level changes in the author's bench marks are given with open circles in the same figure. From Fig. 5, then, we see that the rising velocity was the largest at BM-5 in the period from April to May 23, after which date the activity of BM-5 decreased suddenly and BM-7, installed 60 m to the north of BM-5, acquired a large rising velocity, which lasted until June 5. After that up to June 20 the largest rising velocity was seen at the pile mark 5, a pile further north of BM-7; then after the pile marks situated more north had the largest rising velocity. These curves in Fig. 5 tell us the center of the upheaval movement of the ground migrated from south to north with the lapse of time.

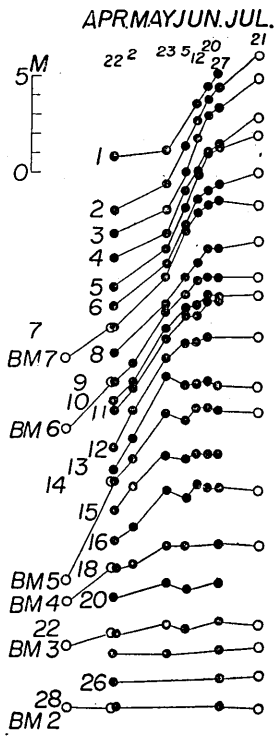


Fig. 5.
Altitude change of pile bench marks as compared with B. Ms. 2~7.

Parallel to this road and about 100 meters to the east runs the railway line from south to north, traversing the eastern foot of Mt. Usu. Due to the topographic changes just described the railway also suffered serious damages. Detailed leveling surveys along the railway were carried out by the Depart-

ment of Railways, and the results were laid at the author's disposal through the courtesy of the authorities. The changes in the altitude of the bench marks distributed along the railway will be seen in Fig. 6. We notice in it that, although the amount of upheaval of the railway bench marks was certainly less than that of the pile marks along the road, the manner in which the upheaval movement proceeded in the two cases was much alike.

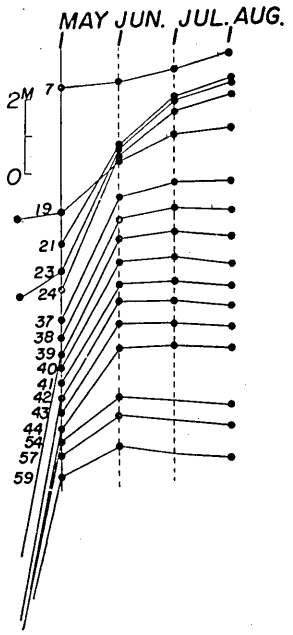


Fig. 6. Altitude changes along the rail-way.

The leveling routes surveyed above all ran from south to north; in other words, the routes ran parallel to the concentric arc of Mt. Usu. So in the second survey a leveling route A, B, ···F, that runs in the radial direction of the mountain and joins the route I at BM-5, was selected. The leveling surveys were made along this route three times on April 21, 22 and July 20 (Fig. 7, A & B). The changes in the level became smaller and smaller to the east, or in other words the lower marks were less elevated than the higher ones, and it appears probable that the center of the upheaval lay on the west side of the road.

These several evidences afforded by leveling surveys made us infer that the activities of Mt. Usu, which began on Dec. 27, progressed in the following

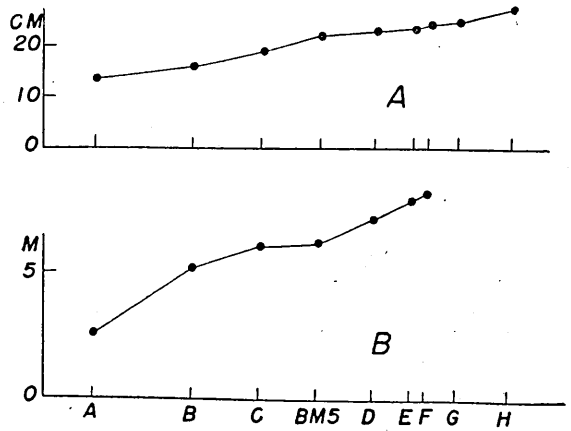


Fig. 7. Levelings in the radial direction.
A; April 21~22. B; April 22~July 22.

way: (1) in the first stage of activities, earthquakes began to be felt by the inhabitants at the northwest foot of Mt. Usu; (2) two months later, the center of seismic activities shifted to Yanagihara, a village situated at the eastern foot of the mountain, and at the same time a conspicuous upheaval movement of the ground became noticeable in the epicentral region; (3) then as time went on, the center of elevation migrated gradually northward, and (4) at last on June 23, 1944, the first eruption broke out near Fukaba village, the area where the elevation velocity is supposed to have been the largest at that time. As soon as the eruptions began certain places remote from the crater began to sink, but the observed amount of subsidence did not exceed 20 cm.

In the above observation, the altitude of the author's bench marks has always been described with reference to that of BM-1, and the altitude of BM-1 has been assumed to have remained unchanged throughout the whole period. For the purpose of discovering any change in the altitude of BM-1, precise levelings were carried out twice between our BM-1 and BM-345 of

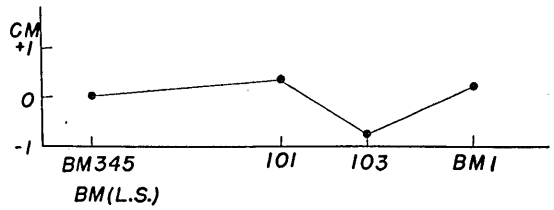


Fig. 8. Change in the altitude difference of BM 1 compared with the BM 345 of the Land Survey.

the Land Survey, which was situated at 3.5 km to the south of BM-1. The change in the altitude difference between these two bench marks in the period from April 19 to July 14 was less than 5 mm, as may be seen in Fig. 8.

In view of the magnitude of the upheaval movement we are dealing with, it would be safe to say that the accuracy of the conclusions will not be affected by the assumption that BM-1 did not change in altitude.

3. Leveling Survey by Means of Pond Surfaces.

At the time of the first and second surveys there had formed three ponds P-1, P-2 and P-3 in Fig. 1 in the paddy-fields in the neighbourhood of BM-6, P-1 being 60 m×80 m and the other two 10 m×10 m in size. We tried to ascertain the daily amount of tilting of the ground and the azimuth of its maximum tilting by making use of the water surface of these ponds. For this purpose we erected wooden poles along the shore lines of the ponds at intervals of several meters, and once every day at a fixed hour the height of

the water surface at each pole was read off. As these ponds happened to be in the region where the crustal deformation was going on most actively, the relative level change of the water surface with respect to two poles widest apart in the direction of maximum tilt exceeded 4 cm in a whole day. This convinces us that the amount of the tiltings observed in this way can be taken as sufficiently reliable. The result obtained is given in Table I. The amount

Table I. Tilting of the ground revealed from the survey by means of the pond surface. I; maximum angle of tilting. Z; azimuth of maximum tilting.

P—1			P—2			P—3		
Period	I	Z	Period	I	Z	Period	I	Z
April	′ ″	N W	April	′ ″	N W	April	′ ″	N W
13~14	3 50	85°	17~18	3 05	83°	17~18	2 25	71°
15~16	4 40	81	18~19	2 40	80	18~19	2 43	71
16~17	4 40	82	19~20	2 30	81	19~20	2 40	71
17~18	5 00	84	20~21	2 20	71	20~21	2 56	71
18~19	5 00	84	21~22	2 20	75	21~22	2 50	68
20~21	2 40	78	22~23	2 30	75	22~23	3 37	67
21~22	4 10	79						

of tiltings in Table I is so large that one might say it is extremely rare that such a great crustal deformation should be caught and observed in the course of its progress. In the calculation of tiltings the sine curve method was employed. Some examples of such curves are shown in Fig. 9. At the time of the third survey the center of upheaval lay in the neighbourhood of BM-7 and it was found necessary to extend the leveling route further north. In this area leveling surveys were rendered difficult by the heavy fall of volcanic ashes, but luckily a new pond (P-4) had formed as a result of the damming-up of the River Sobetsu, the backwater extending to more than 1 km. It was decided, therefore, that this should be made use of to detect the mode of topographic changes in this area. The position and the tiltings of the P-4 will be seen in Figs. 1 and 10. From the survey of this pond we found a

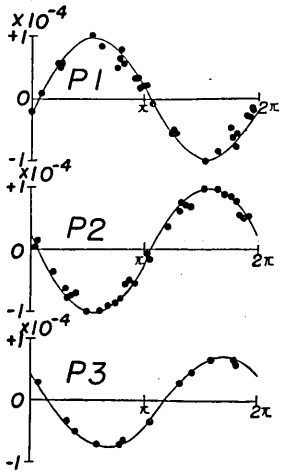
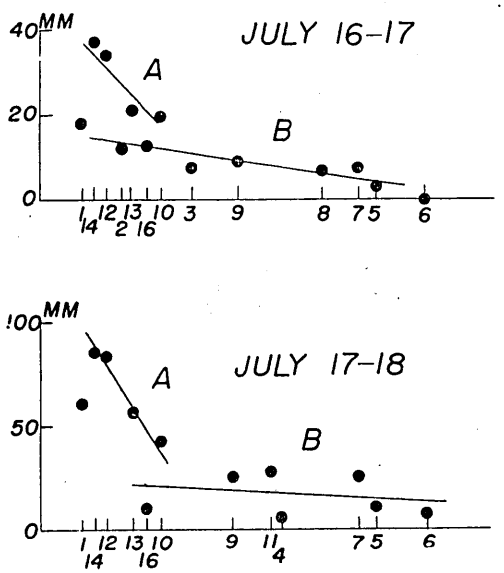


Fig. 9. Tiltings revealed by pond surface.



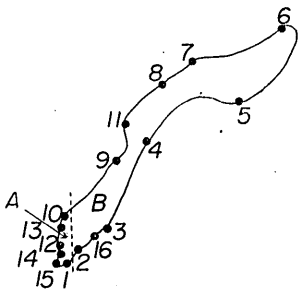


Fig. 10-II.

Fig. 10-I. Tilting of ground revealed by the survey of Pond-4. Location of dots corresponding to respective figures in Fig.10-I are seen in the map of Fig. 10-II. The amount of tilt in the A-part is definitely larger than the B-part.

distinct difference in the mode of crustal deformation between the southern part and northern part of the pond, as to be seen from the two curves, A and B, in Fig. 10. The boundary between the two parts exactly corresponded to the place where the Takinoue lava and the somma lava were in contact in geological ages. The result of the analysis will be seen in Table II and Fig. 11, A & B. The tilting angle in the southern part of the pond was almost 100 seconds per day, while that of the northern part was less than 10 seconds a day. The tilting of the region further north was observed by making use of a small pond which was situated about 100 meters to the north of the pond just described, and the angle of tilting was found to be less than 1 second per day.

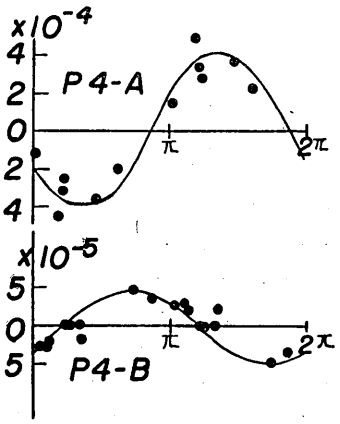


Fig. 11. Tilting of the Pond-4. The amount of tilting of the A-part is larger than the B-part.

Table II. The angle and azimuth of maximum tilt of the Pond-4.

Period	I $\times 10^{-4}$	Z
July 12~13	4·6	N 125° W
13~14	4·0	145
14~15	3·4	165
15~16	4·2	60
16~17	3·6	135
17~18	4·3	117
18~19	4·6	140
19~20	4·6	105

4. Leveling Surveys by Means of the Water Surface of Lake Toya.

In connection with the activity of Mt. Usu, it was considered an important study to know how far the phenomena of crustal deformation due to the present activity extended. It is almost impossible, however, to carry out a precise leveling over the vast area, so the Lake Toya situated to the north of the active area has been used for that purpose.

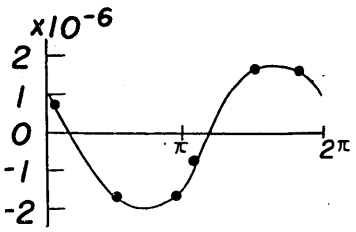


Fig. 12. Tilting of the Lake Toya.

Table III. Leveling survey by means of the water surface of Lake Toya.

No. of Bench Mark	T-1	T-2	T-3	T-4
Location	Toya Hot Spring	Nakano-Shima Is.	Muko-Toya	Takinoue
II. Observed date	July 20	July 20	July 19	July 19
Hour	13h	9h	16h	10h
Temperature	24°C	25°C	25°C	22°C
Wind	gentle	gentle	none	none
H' (cm)	231.37		214.36	106.54
△H' (cm)	−1.12		−0.25	0.00
H (cm)	232.49		214.61	106.54
I. Observed date	Apr. 22		Apr. 22	Apr. 22
H (cm)	342.71		324.14	217.68
Difference(II-I) (cm)	110.22		109.53	111.14

In the second survey, bench marks were placed at four points along the lake shore, namely, Takinoue, Toya Hot Spring, Muko-toya and Nakanoshima. The height difference between each benchmark and the surface of the water was measured as carefully as possible. Fortunately the weather was extremely calm and the water smooth when the survey was made, and we believe the probable errors involved in the observed values are less than 2 mm. The resurvey took place in July, and on that occasion a mercury manometer and a Y-level were used for greater accuracy. Among the four bench marks that of Muko-toya was the most distant from the active area, and we assumed that the altitude of this mark remained unchanged for the three months from April to July. By referring to this mark, the amounts of upheaval of the bench marks of Takinoue and Toya Hot Spring were measured as 16.1 mm and 6.9 mm respectively. The angle of tilting in the lake region calculated from these surveys was 20×10^{-4} and azimuth of maximum tilting was N 12° E.

In conclusion the author wishes to express his cordial thanks to Dr. T. Minakami for his kind advices in the course of the field surveys.

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11. 有珠山の活動と精密水準測量

地震研究所　表　俊一郎

北海道有珠火山は明治43年大活動を行つて以來靜穩な狀態をつづけてきたが，昭和18年暮より再び活動を開始し，12月27日より多數の地震の發生していることが北麓で感知せられるやうになり，次で翌年1月には東側の山麓で著るしい土地の隆起運動が認められるようになつた．この隆起地帶は次第に北へと移行しついに6月23日フカバ附近に新火口を生じて噴火を行うようになつた．このような著るしい地殼變動現象がその進行の過程に於て捉へられて調査が行われることは極めて興味あることであるので著者は昭和19年3月，4月及び7月の3回にわたり現地に赴き精密水準測量を實施し，主として噴火を始める迄の期間に有珠山麓で如何なる地殼變動が行われたかを明らかにするために調査を行つたのでそれらの結果がこの報告に於てのべられている．