3. *Tilt of the Earth's Crust observed at the Asama Volcano.*

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1. Mt. Asama, which is situated on the boundary of Gumma and Nagano Prefectures, about 100 km. north-west of Tokyo, is one of the most active volcanoes in Japan. From ancient times it has often repeated violent eruptions, among which that of 1783 was the largest. In the case of this eruption, 1150 lives were lost and several villages were buried under mud-flows. The lava-flow which was issued from the crater by this eruption covered the greater part of the north slope of the mountain, and is called now Oni-no-osidasi.

The mountain is a composite volcano made of acidic lava and gravels and rises 2542 m. above the sea level. As classified by the character of its eruptions, it belongs to the Stromboli type. Its active period seems to come at the interval of several tens of years. The recent activity of the volcano commenced in September of 1929, and has continued since.

Several geophysical researches has been made at this volcano, among which the observations made by Prof. Omori[1] of the volcanic earthquakes and other phenomena are most remarkable. There has been made, however, no research, as far as the author is aware of, concerning the deformation of the earth's crust connected with the eruption of this volcano.

2. In recent years, levelling surveys have revealed in several cases the deformation of the earth's crust associated with the eruption of a volcano. As the examples of these cases, we can point out the eruptions of the Sakurazima Volcano, in 1914[2] the Usu Volcano in 1910[3] and the Komagatake Volcano, Hokkaido, in 1929[4].

These levelling surveys did not, however, tell us in what manner

1) *Bull. Imp. Earthq. Inv. Comm.*, **6** (1912-1914); **7** (1914-1919).
2) F Omori, *Bull. Imp. Earthq. Inv. Comm.*, **8** (1914-1922).
3) F. Omori, *Bull. Imp. Earthq. Inv. Comm.*, **5** (1911-1913), 1-38, 101-107.
4) Ch. Tsuboi, *Bull. Earthq. Res. Inst.*, **8** (1930), 298.

the deformation of the crust arround a volcano makes its development during the active period of the volcano. In connection with this question, a pair of clinographs was installed, in the case of the last eruption of the Komagatake Volcano in 1929, at the north slope of the mountain and the tilt of the earth's crust was observed for about 6 months. By this observation we could recognize the existence of certain correlations between the activity of the volcano and the tilt of the crust arround the volcano, though they were not very distinct owing to the facts that the eruption was of a single explosion having no subsequent remarkable event and that the observation was commenced after that main explosion.

In 1929, T. A. Jagger and R. H. Finch[5] reported about the remarkable correlation existing between the tilt of the ground observed at the Hawaiian Volcano Observatory and the height of the molten lava in the Halemaumau pit, Kilauea Volcano.

The present writer has long been considering that it is very promissing to execute a clinograph observation at Mt. Asama for the purpose of getting some informations regarding the problem described above and also, if possible, the mechanism of the eruption and the under-ground structure of the volcano. The idea has not been realized under certain circumstances until April of this year, when it siezed the first opportunity to go out in the day-light, and the observation was commenced in the summer of the same year. The results of the observation harmonize well with those obtained by Jagger at Kilauea, if we take into consideration the difference of the characters of the eruptions of the two volcanoes.

3. The present observation was commenced on June 3, 1932, with a pair of clinographs, at Komoro, a village which lie at the south-west foot of the Asama Volcano. The clinograph is essentially a horizontal pendulum made of fused quartz. The deflection of the pendulum is recorded photographically. The pendulums were installed in a masonry refrigerating cellar, situated at the north suburb of the village of Komoro, in such directions as to record respectively N-S and E-W components of tilt of the ground. The cellar is built on a natural bed of consolidated volcanic scolia and gravels ejected by some pre-historical eruptions. It belongs to the Zyunsuikawan Silk-worm Egg Company and is used in summer for the storage of silk-worm eggs. The sensibility of the instrument was so adjusted, at the beginning of the observation, that a

5) *Bull. Seis. Soc. Amer.*, **19** (1929), 38.

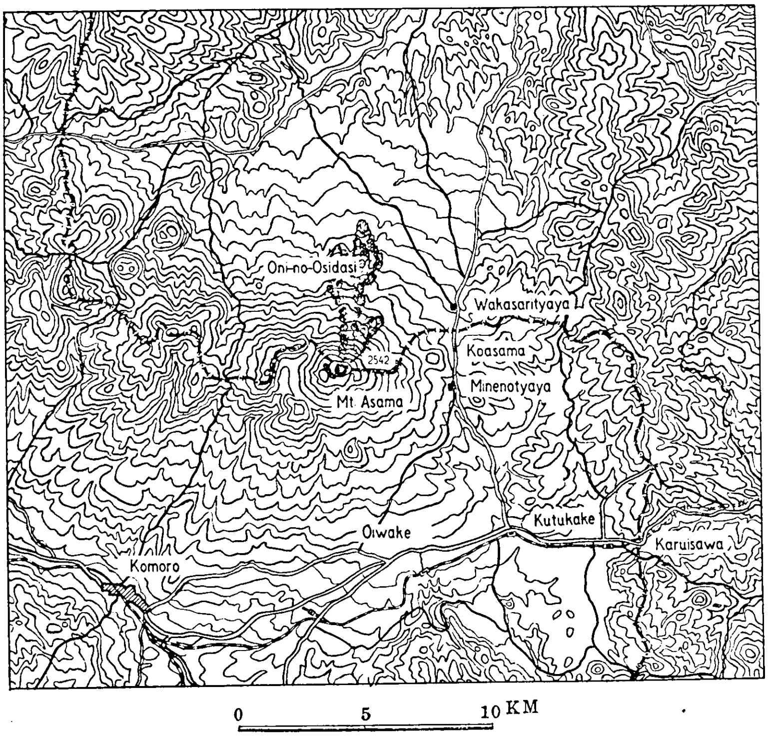

Fig. 1. Map showing the Asama Volcano and the vicinity.

deflection of 20 mm. is produced on the record against the tilt of the ground of 1 sec. of arc. The sensibility was examined since then many times by measuring the period of free oscillation of the pendulum. The time-marks on the records were introduced at 6h and 18h of each day. The air temperature and humidity in the cellar were kept prety constant during the period of the present observation.

The installation of the instrument was finished at 21h 30m of June 3, and the observation has been continued since. The attendance to and the manipulation of the instrument have been done by Mr. Oi of the Komoro Primary School.

4. Fortunately enough, on June 4, the next day of the installation of the instrument, a great explosion took place at 20h 29m, with a loud detonation sound. This explosion was so large that the ash-precipitation was experienced in abroad area arround the volcano. At Nagano, which is distant some 40 km. from the volcano, the quantity of the ash-precipitation was measured to be 50 cc./m^2. The detonation sound reached as far as

200 km. This explosion was followed then by smaller ones, which occurred at 4h 20ma nd 12h 30m of June 5. Since then many eruptions of various magnitude have occurred, which exceeded 70 in number at the end of August. The magnitude and the time of occurrence of each eruption was kindly reported by Mr. Utibori, the host of the Minenotyaya Cottage (see Fig. 1). Eruptions reported in the "Kisyô-yôran", issued from the Central Meteorological Observatory, were also taken into considerations. At Minenotyaya, which is distant only 5 km. from the crater, even a minute eruption, which cannot be recognized at distances, especially in rainy or cloudy weather, is observed, while the magnitude of the eruption seems to be judged more exactly by distant observations given in the Kisyô-yôran.

The eruptions occurred during the period of the present observation are listed in the following pages. The list includes eruptions and other volcanic events reported both by Mr. Utibori and by the Kisyô-yôran.

Date	Time of Occurrence		Remark
	h	m	
June 4	11	30	Low detonation.
	20	25	Strong explosion; detonation sound being heard at Minenotyaya. Oiwake, Ueda, Sugadaira, etc. Detonation sounds like gun-shots were heard at 20h 34m at Gihu Observatory, which is distant so far as 200km. from the volcano. An erathquake was felt at Minenotyaya and Oiwake. Ashes fell at Koasama, Minenotyaya, Togemati, Nagakubo, etc. The quantity of ash-fall was 30 gr./m² at Nagakubo and 50 cc./m² at Nagano.
5	3	53	Explosion with rumblings. Windows vibrated slightly at Oiwake. Black smoke flowed towards north.
	5	40	Low detonation. Ashes fell at Osidasi.
	12	27	Rumblings and smoke emission.
7	14	00	Small eruption. Ashes fell at the north of Minenotyaya.
8	8	00	Small eruption. Ashes fell at Minenotyaya & Koasama.
9	20	20	Do.
10	2	—	Weak detonation.
	6	18	Rumblings were heard for 20 minutes.
12	7	30	Rumblings were heard till 12h. White smoke was emitted at times.
13	11	—	Detonation. Ashes fell at Osidasi.
14	17	09	Explosion. Ashes fell in all part of Kita-saku district and a part of Minami-saku and Tiisagata districts. Ashes fell for 8 minutes at Oiwake.
21	—	—	Rumblings.

(to be continued.)

(*continued.*)

Date		Time of Occurrence		Remark
		h	m	
June	22	9	58	A rather conspicuous earthquake.
	24	14	57	Explosion. Weak earthquake was felt at Minenotyaya, Oiwake and Kutukake. Sands and stones as large as an cube-sugar fell near Wakasarityaya.
		19	42	Explosion. Weak earthquake was felt at Oiwake.
	25	12	—	Small eruption. Ashes fell at Sengataki and Kutukake.
		18	—	Do.
		22	45	Small eruption. At Oiwake windows vibrated.
	26	4	55	Smoke emission. Ash-fall at Minenotyaya.
	27	—	—	Rumblings heard from 3h till 5h 30m.
	28	9	02	Loud detonation and explosion. Weak earthquake was felt at Oiwake. Sound reached a considerable distance. Sands fell at Minenotyaya for 25 minutes.
		18	21	Detonation.
	29	15	—	Ashes fell a little at Minenotyaya, Kamahara and Wakasarityaya.
	30	14	—	Ashes fell at Osidasi.
July	1	5	25	Small eruption. Ash-fall at Wakasarityaya.
	2	19	—	Small eruption. Ash-fall at Minenotyaya. Rumblings were heard all the day.
	3	4	52	Loud detonation and explosion. At Kutukake detonation sound was heard like a thunder and vibrations were prety strong. At Togemati low explosion sound was heard and ashes fell for 5 minutes. At Minenotyaya the explosion sound was like a gun-shot and stones as large as 2 cm. dia. have fallen.
		5	03	Eruption.
		5	38	Small eruption.
		10	50	Small eruption. Smoke emission continued till 11h 30m.
		16	47	Do. Smoke emission continued till 17h 30m.
		20	25	Do.
	4	—	—	Small eruptions at about 4h, 6h and 11h 30m.
	5	—	—	Small eruptions at about 7h, 14h and 20h 30m.
	9	14	30	Small eruption.
		18	30	Do.
	10	4	37	Small eruption. At Minenotyaya, rumblings were heard and ashes fell for 2 hours.
		9	—	Small eruption. Ashes fell at Minenotyaya.
		11	20	Smoke emission. Ashes fell at the E base of the mountain.

(*to be continued.*)

(*continued.*)

Date	Time of Occurrence h	m	Remark
July 10	12	40	Do.
	13	40	Small eruption. Ashes fell for 25m. at Minenotyaya.
	16	—	Smoke emission for 30m.
	20	—	Much smoke emitted. Ashes fell at N of the mountain.
11	10	16	Small eruption.
	11	10	Do. Ashes fell at Minenotyaya.
	14	07	Do.
	19	20	Do.
	20	20	Do. Sands fell at Minenotyaya.
12	3	30	Eruption. Black smoke was driven towards ES. Ashes fell for 40m. at Minenotyaya.
	7	15	Smoke emission.
	13	50	Smoke emission with low detonation sound.
	15	20	Small eruption.
	18	55	Smoke emission. Ashes fell for 5m. at Minenotyaya.
13	15	20	Smoke emission for 10m.
	19	20	Small eruption.
14	12	30	Smoke emission for 5m.
15	11	10	Smoke emission.
	14	—	Low detonation.
	17	20	Small eruption.
16	8	—	Small eruption. Ashes fell a little at Minenotyaya.
	11	—	Do.
	15	—	Smoke emission.
17	—	—	3 small eruptions during 9h and 16h. Ashes fell a little at Minenotyaya.
18	3	36	Small eruption with rumblings.
	11	26	Rumblings. A large quantity of black smoke was emitted
19	6	15	Small eruption. Ashes fell much at Minenotyaya.
	8	—	Do.
	11	15	Do.
20	7	30	Small eruption with much smoke emitted.
	8	15	Smoke emission for about 1 hour.
21	0	—	No smoke.
	4	45	Smoke emission without rumblings.

(*to be continued.*)

(continued.)

Date	Time of Occurrence h	m	Remark
July 21	14	20	Smoke emission after 20 minutes' rumblings.
	17	—	Rumblings for about 40m.
	19	20	Rumblings.
22	17	—	Small eruption and rumblings.
	19	35	Do.
23	7	35	Loud detonation. Ash- clouds were driven towards NE.
	8	—	Small eruption and rumblings.
	12	20	Detonation.
	13	—	Small eruption with rumblings. Ashes fell at Kutukake.
	18	35	Small eruption with loud rumblings.
	19	08	Smoke emission.
24	9	50	Rumblings.
	11	30	Do.
	15	40	Small eruption. Much black smoke.
	17	41	Rumblings.
25	9	40	Rumblings and smoke emission.
26	7	—	Low rumblings.
29	5	10	Rumblings. A large quantity of black smoke was emitted.
	14	17	Small eruption.
	14	35	Rumblings. Smoke emission. Ashes fell for 5m. at Minenotyaya.
30	11	08	Small eruption. Much black smoke.
Aug. 4	5	—	Smoke emission. Ashes fell at Minenotyaya, Wakasarityaya and Koasama.
	10	50	Smoke emission without rumblings.
	11	45	Smoke emission. Ash-clouds were driven towards NE.
	17	—	Do.
6	6	—	Small eruption.
9	4	—	Smoke emmission.
	11	20	Do.
20	—	—	Smoke emission.
27	11	40	Smoke emission without rumbings.
Sept. 10	15	30	Small eruption with thunder-like detonation sounds. Ashes fell at Minenotyaya and Osidasi.
20			Detonation.
21	10	58	Explosion. The column of smoke was observed well at Nagano, and was estimated by a theodolite to be 4100m. high above the sea level.
	12	50	Small eruption.

In the Kisyô-yôran is given, besides these reports of eruptions of the volcano, the frequency of the volcanic micro-seisms observed at the Oiwake Observatory. It is listed as follows:

Number of volcanic micro-seisms observed at the Oiwake Observatory.

Day \ Month	June	July	Aug.	Sept.	Day \ Month	June	July	Aug.	Sept.
1	—	10	5	0	17	—	7	1	0
2	—	9	1	1	18	—	5	2	0
3	—	14	3	1	19	—	1	1	0
4	6	8	7	0	20	1	5	1	0
5	5	3	1	0					
6	3	0	1	1	21	—	5	0	2
7	3	0	0	2	22	—	3	0	5
8	1	1	1	0	23	—	21	0	8
9	1	3	0	1	24	13	16	0	5
10	3	12	0	0	25	35	6	0	5
					26	26	8	0	5
11	—	9	1	0	27	1	0	2	5
12	6	11	3	0	28	9	7	0	4
13	9	5	3	0	29	6	13	1	0
14	4	1	0	0	30	2	9	0	0
15	3	5	0	0					
16	—	12	0	0	31		3	3	

5. Fig. 2 is the reproduction of the tilt-records obtained by the clinographs during the period from June 3 to Sept. 10, 1932. In the figure are also shown, in parallel with these tilt-curves, the daily numbers of the volcanic micro-seisms observed at Oiwake, and the eruptions listed above. The thin vertical lines under dates show the noon of that day. The great explosions are indicated by large dots, while small eruptions, smoke emissions and detonations are all represented by small dots. Very minute volcanic events are omitted in the figure. The position of each dot represents the time of occurrence of the event, while the daily number of micro-seisms is assigned to the noon of each day. The letters E, W, S and N attached to the tilt-curves show respectively the directions towards which the ground tilt *down*. The deviation of E–W tilt-curve to the side of the letter E shows therefore that the ground tilted in the sense *east down and west up*.

As can be noticed in the figure, eruptions seem to occur in groups, and the largest one stands generally at the head of a group. There are cases in which the greatest eruption in a group is preceded by one eruption or two of smaller scale, but it never occur at the rear of a group. Series of small eruptions, such as appeared in the present

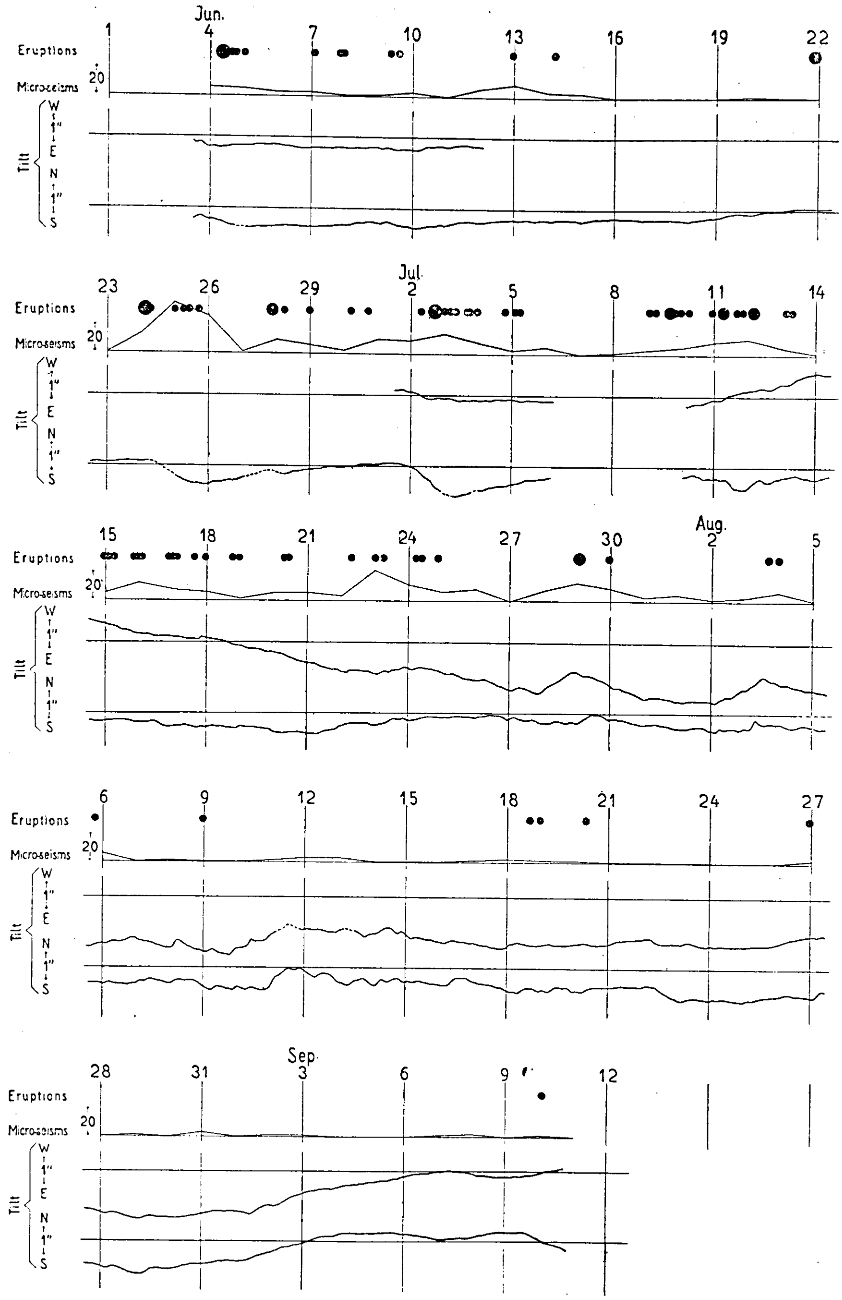

Fig. 2. Tilt-curves.

observation during the period from July 15 to July 25, seems to come to an end without resulting to any remarkable eruption.

These feature of eruptions may be understood by the speculation that the quantity of energy spent by the first eruption must be greater than those spent by the subsequent ones, because the volcano shaft is probably corked firmly at the time of the first eruption. When the corking of the shaft is not so firm, the eruptive energy will be dissipated by series of small eruptions. This speculation harmonizes well with the mechanism of the tilt of the earth's crust considered later.

The activity of such a volcano as Asama is very difficult to estimate. We may however take without much errors the frequency and magnitude of eruptions as a measure of the quantity. An alternative measure of the activity of a volcano will be the frequency and magnitude of seisms of which the origin is under the volcano.

Indeed, we can notice in Fig. 2 that the frequency of the volcanic micro-seisms is, generally speaking, in a considerable correlation with the frequency and magnitude of eruptions. In making this comparison however, volcanic earthquakes were all neglected, because they are very few in number compared with the micro-seisms and the neglection of them will have no effect upon the general feature of the matter. Small discrepancies in the parallelism of the two quantities have probably their origins in the difficulty of estimating the magnitude of an eruption.

In the recent number of the "Volcano Letter", A. E. Johnes and T. A. Jagger[6] have reported that the sismicity observed at the Hawaiian Volcano Observatory is related closely with the lava-inflow of the Halemaumau. It is interesting that there is a similarity also in this respect between the Asama and the Kilauea, notwithstanding the difference of types of the two volcanses.

Now we will proceed to study how the tilt of the earth's crust found by the present observation is related to the activity of the volcano. In the first place, we can find in Fig. 2 that the daily variation of tilt, which is mainly caused by the thermal stresses produced in the ground by solar radiation and amounts usually to 1″ or 2″, is very small at Komoro. This is likely due to the sandy soil of the place. We will find further that there are fluctuations of the tilt of which the period is about a week. This is, we think, probably due to the variation of the same period of the atmospheric pressure. Other weather conditions, such as rainfall, do

6) *Volcano Letter*, Feb. 4, 1932.

not seem to have any remarkable effect on the tilt observed.

We can see, referring to N-S tilt-curve, that the earth's crust began to tilt from its mean position on June 18, six days before the great explosion of June 24, making since then a steady, constantly increasing tilt until the day of occurrence of the explosion. Similar tilts will be found before the explosions of June 28, July 3 and July 29. The explosion of June 4 must also have had a similar tilt. These tilts are all directed towards NW.

This feature of tilt will likely mean the accumulation of the volcanic energy and the consequent increase of the pressure under the mountain, resulting in the deformation of the crust. It will probably be due to some local structure of the crust near the observation station that the tilt is not radial with respect to the mountain but is circumferential. An alternative explanation of the direction of tilt will be that the tumescence centre of the volcano is not coincident with the crater of the volcano but lies somewhat south of the mountain.

This tilt of the crust, which proceeds the occurrence of a group of eruptions, usually stops increasing at the same time with, or a little time before the first eruption of the group. Then the crust begins generally to tilt to the opposit sense, recovering to the original state with the subsequent eruptions. This will probably mean that the accumulated energy of the eruption was spent by the sequence of eruptions, and the crust returns to its original state because of the decreased pressure under it. The variation of the tilt of this type are to be seen by the groups of eruptions extending respectively from June 24 to June 26, from July 3 to July 5, etc.

When the dissipation of energy by series of eruptions balances with the accumulation of energy, there will be no tilt. If the accumulation velocity surmount the velocity of dissipation by eruptions, the crust will swell out notwithstanding the eruptions occurring. The feature of the tilt-curve extending from July 7 to July 21 will be regarded as an example of such a case.

When the accumulated energy is not sufficient to break the crater plug, there will occur no eruption, but some deformations will be produced arround the volcano. On the contrary, when the crater plug is not perfect, there will be no remarkable deformation of the earth's crust, though a sequence of small eruptions will be observed.

Thus the results of the present observation will be explained, without conflicts, by the hypothesis as follows. The increase of the pressure of magma under the Asama Volcano by the magmaic differentiation, which appears afterwards as the a group of eruptions, causes the deformation of the crust and accordingly the deflection of the clinograph installed at the foot of the mountain, before the commencement of the group of eruptions.

In the case of the Kilauea Volcano, the under-ground pressure will, in the first approximation, be equal to the hydrostatic pressure of the column of the molten lava in the crater, but in the case of Mt. Asama individual feature of the tilt of the crust arround the volcano depends on the velocity of increase and decrease of the pressure under the volcano and also on the condition of the crater bottom of the volcano at the time under consideration.

Detailed elucidation of the phenomena depends largely on the execution of the observations similar with the present one at different places arround the volcano. For this purpose, we are now going to make a observation at Minenotyaya. With the accomplishment of that observation, we hope that we can give a forecast of the commencement of the active period of this volcano, even if we cannot know the magnitude of individual eruptions.

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3. 淺間山麓に於ける地表傾斜變化の觀測

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火山の噴火に伴つて地殼の變形が生じる事は，有珠火山，櫻島火山，北海道駒ヶ岳火山の噴火の場合に，水準測量に依つて確かめられた處である．然し乍ら，此の地殼の變形が火山活動の道程と時間的に如何なる關係を以て起るものであらうか，と言ふ疑問に對して吾人の知識は餘り豐富ではない．此の觀測は此の問題を明にする爲と，更に出來れば火山活動の機巧を覗ふ爲に企てられたものである．

觀測に用ひられた器械は熔融水晶製の石本式傾斜計である．觀測場所は淺間山の西南麓なる小諸町の郊外，純水館蠶種會社の冷藏地下室である．觀測上の實際の仕事は小諸補習學校の大井一夫氏を煩はした．又噴火記事に就て內堀定市氏の報告に據るものが多い．著者は此處に上記蠶種會社と大井氏內堀氏とに深謝の意を表する次第である．

觀測の結果は第二圖に於て見られる．同圖に於ては同時に，噴火回數と追分測候所觀測の火山性微動の回數を擧げてある．圖に於て E. W. N. S の文字で曲線が其の字の側に偏れた事に依つて，其字の表す方向へ地面が傾いた事を示す．

圖から見られる如く，(1) 噴火は群を爲して起り，概して群の先頭に大きな噴火が起る樣である．

(2) 火山性微動の回數は大體に於て噴火と並行してゐる樣に見える. (3) 噴火群の起る五六日前から地殼の傾斜變化が起る. 而して最初の噴火か又は其の少しく前に傾斜變化の方向は反對になり, 其の後に續く噴火と共に原狀に復する. 噴火前の傾斜の方向は北西であつて噴火時の傾斜の方向は南東になる. 此の樣の例は六月四日, 六月二十四日, 六月二十八日, 七月三日, 七月二十九日等に始まる噴火群の前後に見られる. (4) 噴火を爲しつゝ西北に傾き引續いて東南に傾く場合がある. 例へば七月九日以後の噴火群である. 此の樣の場合には餘り大きな噴火は起らぬ樣である.

此等の噴火と傾斜變化の關係は次の樣の考で說明出來る. 卽ち, 岩漿の分漿作用によつて岩漿內の壓力が次第に高くなつて來ると, 地殼が押上げられて地表の傾斜變化が起る. 而して噴火群と共に壓力の減少を來し, 從つて地殼は元に復する. 殆も餅を燒く時に吾人が屢ゝ經驗する現象の大規模なものであると考へられる. 但し傾斜の方向が, 山の方向, 又は其の反對方向に向はずして, 之と直角の方向へ向く事は恐らく觀測所の附近の局部的地殼構造によるものと考へられる.

且又噴火群中の個々の噴火の大小等は其の時々の活動勢力の蓄積と其の消失の速さ, 火口底の狀態等に因つて定まるものであらう.