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34. *The 1968 Eruption of Volcano Arenal, Costa Rica.*

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1. Introduction

Since Volcano Arenal in Central America has no record of historical eruption up to July, 1968, we can not find even the name of Volcano Arenal in *Catalogue of the Active Volcanoes of the World, Part VI; Central America*. On July 29 and 31, 1968, however, catastrophic eruptions suddenly took place on the western flank of Volcano Arenal, which resulted in the death of 78 persons and complete destruction of the dwelling houses and cultivated land of the villages at the western foot of the volcano, Pueblo Nuevo and Tabacon.

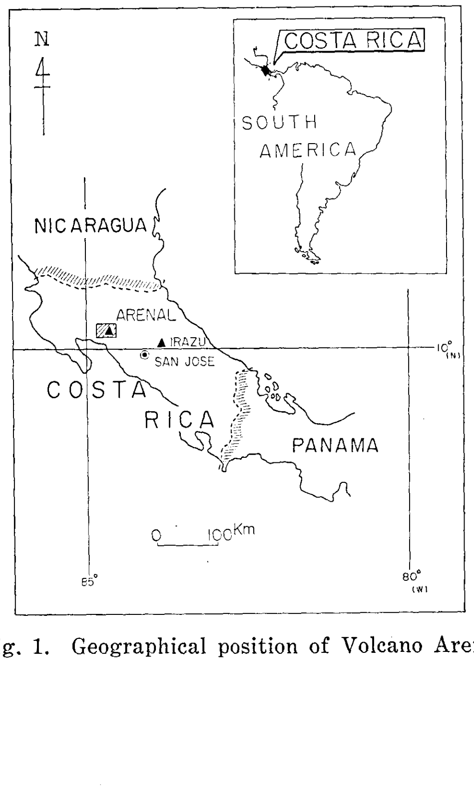

Fig. 1. Geographical position of Volcano Arenal.

In order to prevent further catastrophe the Costa Rican Government requested volcanologists and seismologists in Japan and other countries to investigate the eruption of Volcano Arenal for the purpose of getting some useful suggestions from the volcanological viewpoint. For that purpose, we carried out not only field investigation of the eruption but also temporary seismometrical observation and geothermal survey of Volcano Arenal during the one-month period between the end of August and the end of September of the same year.

2. A brief description of the 1968 eruption of Volcano Arenal

Volcano Arenal is situated in the north-western part of Costa Rica, more precisely at 10° 27′ 45″N latitude and 84° 42′ 48″W longitude. It is topographically a regular cone of volcano and the altitude is 1638 m above sea-level.

Three craters were formed on the west flank of Volcano Arenal at about 7 h 30 m, July 29. Of these newly formed craters, the largest one is at the altitude of between 1050 m and 1150 m and the other smaller ones are at the altitude of between 1200 m and the summit.

After the first explosive eruption, it lasted with ebbs and flows for more than fifty hours. The first eruption and the July 31 eruption,

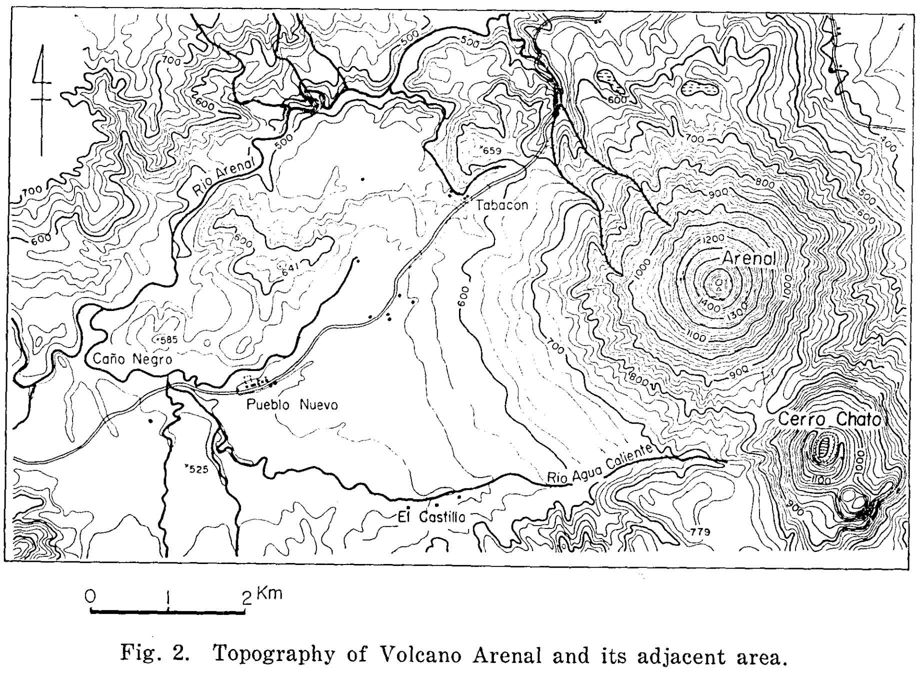

Fig. 2. Topography of Volcano Arenal and its adjacent area.

however, were the strongest, which caused catastrophic damage to the western skirt of the volcano. Besides these three craters we found fumarolic activity on the summit of Volcano Arenal. It should be noted that all these new craters as well as the center of the fumarolic area are on a narrow linear belt extending from the summit toward the WSW direction, as can be seen on the map of Fig. 3. Therefore, the recent eruption of Volcano Arenal can be classified as fissure eruption and the fissure might have been produced by a series of severe earthquakes which occurred just before the present eruption. Although it is important to make clear whether the above-mentioned fissure extends to the opposite side or the east flank of the volcano or not, we have no evidence relating to the extension of the fissure.

In the recent eruption of Volcano Arenal, we could find various types of eruption, that is, an explosive eruption of vulcanian type in which lava blocks and volcanic bombs were ejected from the craters with high initial velocity, an eruption of the nuée ardente in which a large amount of lapilli, sand and volcanic ash rushed on the villages at the western foot, and outflows of the aa-lava stream from the lowest crater.

It is necessary to describe here an outline of development of the

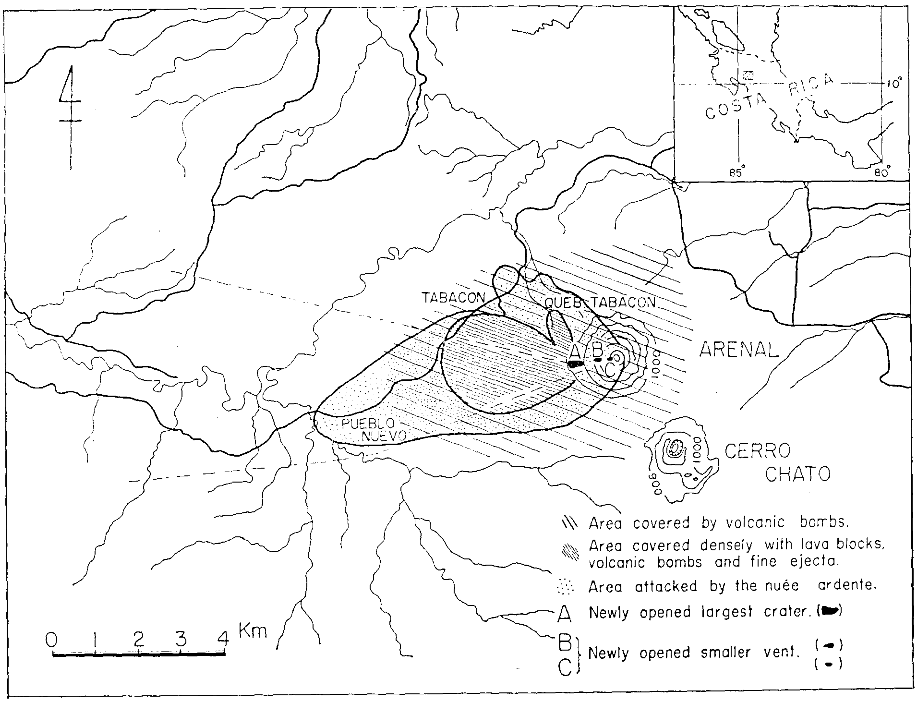

Fig. 3. Locality of the newly formed craters and distribution of the ejecta by the July 29 and 31 eruptions.

eruption of Volcano Arenal based on not only our investigation but also the report by W. G. Melson, R. Sáenz R. and H. H. Waldron.

1) July 29 through 31

An explosive eruption took place at about 7 h 30 m July 29 after a series of severe earthquakes for several hours. On July 31 another strong eruption occurred. The catastrophic disaster was caused mainly by these two violent explosions.

2) July 31 afternoon through August 3

Volcano Arenal did not show any marked activity and a small quantity of volcanic ash was ejected during this period.

3) August 3 through 10

The volcano became a little more active and a large amount of ash was ejected.

4) August 10 through September 13

According to our observation from the air, we found fumarolic activity on and around the top of Volcano Arenal and vapour from the newly formed craters. However, we did not find any fumarolic activity on the east flank of Volcano Arenal and on the earth's surface of Cerro Chato, an extinct volcano, which is located at 2.5 km SE of the top of Volcano Arenal. The inhabitants of Fortuna village who had evacuated soon after the first explosion began to come back to their residences after the beginning of September.

5) September 13 afternoon through 19

A minor eruption took place at about 15 h 40 m September 13 and a strong explosive one at 21 h 49 m September 16. Volcanic ash fell abundantly on Fortuna village where we were carrying out seismometrical observation. On account of the strong eruption and heavy ash fall, the Fortuna villagers evacuated again to Florencia, Quesada and other towns.

6) September 19 through October

After the explosive eruptions lasting for five days, fresh lava outflowed from the lowest and largest crater in the form of aa lava stream toward Quebrata Tabacon. According to the report by Melson and Sáenz the lava stream on October 17 was estimated to be 1000 m long, 300 m wide and 25 m thick.

Rodorigo Sáenz made not only the seismometrical observation at the new observatory which was established at the northern foot of Arenal, but also the investigation of the new lava flow from the lowest crater.

On the map of Fig. 4, the locality of the lava flow at the beginning of April, 1969, is illustrated according to his survey.

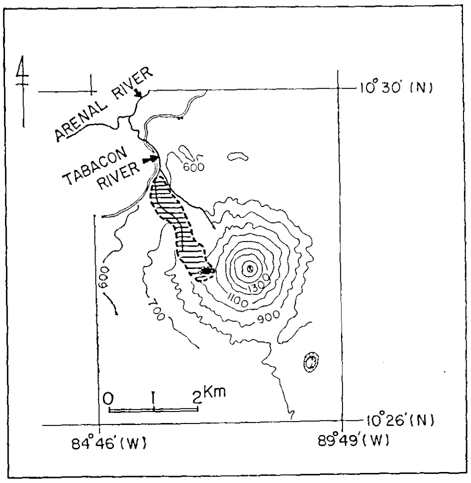

Fig. 4. Hatched area: The locality of the 1968 lava-flow from the lowest crater of the Volcano Arenal (After R. Sáenz R.)

3. The 1968 explosive eruption and nuée ardente of Volcano Arenal

In order to study the nature and intensity of the recent eruption of Volcano Arenal, we made a series of field investigations not only in west side of the volcano but also on its summit and other sides by means of plane and jeep or on foot.

As to the geographical distribution of the present ejecta, it is one of the remarkable characteristics that a lot of lava blocks and volcanic bombs of large size reached as far as more than 4 km in various directions and made big holes on the ground. The holes made by the fall of bombs are shown by the photographs in Figs. 17 and 18. The flight distance of these bombs indicates clearly that the explosive eruptions on 29th and 31st of July were extremely strong and the initial velocity of ejecta and the acted pressure at the moment of eruption might be as remarkable as those of Mt. Asama.

As one of the present writers discussed before, flight motion of ejecta, which is more than 50 cm in their mean diameter, is not so much affected by resistance of air and wind.

We investigated the location of big holes made by the fall of big bombs and the angle at the time of fall to the ground, which was sometimes possible to be measured by the number of the trees just before the fall. Since a big bomb fell in the forest at Fortuna village, we could measure the following necessary elements for calculating the initial velocity of the bomb at the moment of eruption:

x_0: horizontal distance from the lowest crater to the hole made by bomb,
y_1: altitude of the lowest crater,
y_2: altitude of the falling point,
$y_0=y_1-y_2$: difference in altitude between the above two places,
θ: mean slope angle between the crater and the location of the hole made by the bomb,
φ: fall angle to the horizontal plane,
α: emission angle at the crater.

Among three kinds of angle mentioned above, we have the following relation.

$$\begin{cases} x_0=3700\ \mathrm{m}\ , \\ y_1=1050\ \mathrm{m},\ y_2=380\ \mathrm{m}\ , \\ y_0=y_1-y_2=670\ \mathrm{m},\ \tan\theta=y_0/x_0\ , \end{cases}$$

$$\tan\alpha=\tan\varphi-2\tan\theta\ ,$$

$$\varphi=55^\circ,\ \alpha=46.^\circ8\ ,$$

$$\text{initial velocity: } v=196\ \mathrm{m/sec}\ .$$

We obtain 196 m/sec as the initial velocity of the bomb at the crater from the above method. According to our past investigation of distribution of the volcanic bombs at Mt. Asama and other volcanoes in Japan, the initial velocities of the bombs which had been ejected by the same eruption showed approximately a similar value, though they were markedly different in respective eruptions.

It is evident that the bomb mentioned above was ejected by the strong eruption on July 29 or 31. According to the information from villagers at Fortuna, it might be one of the bombs from the first eruption. On the other hand, a lot of big bombs in the first eruption fell on Pueblo Nuevo village, which is located about 4 km from the lowest crater. Since the initial velocity of ejecta by the earlier explosive eruption would be not so much different from that by the later one, it is reasonable to estimate that the initial velocities of ejecta in these two big eruptions were in a range from 180 m/sec to 200 m/sec. If we assume that the pressure and the initial velocity of ejecta were in the Bernoulli's relation at the moment of eruption, the pressure (P) for the two strong eruptions is given as follows;

$$P=\frac{1}{2}\rho v^2 .$$

$$\fallingdotseq 400 \text{ atm. press .}$$

On the other hand, we carried out the volumetry of the total ejecta based on our field investigation with respect to the geographical distribution of ejecta, the thickness of fine ejecta and the volume of the newly formed craters. As the result, the total volume of ejecta (V) is given as follows, though it is a rough estimation;

$$V=2\times10^{13}\text{ cm}^3 .$$

If the mean bulk density of the ejecta is assumed as 2.0, we obtain the total mass of ejecta (M);

$$M\fallingdotseq\rho V=4\times10^{13}\text{ gr} .$$

As the main part of ejecta excluding the lava stream is from the big two eruptions on 29th and 31st of July, the total kinetic energy of the present eruption of Volcano Arenal is given approximately as follows;

$$E\equiv\frac{1}{2}Mv^2\longrightarrow10^{22}\text{ ergs} .$$

The nuées ardentes on July 29 and 31

In the 1968 eruption of Volcano Arenal another characteristics of the geographical distribution of ejecta are the accumulation of fine ejecta at the western skirt of the volcano, which is carried by the nuées ardentes.

It is usual that fine ejecta including lapilli, sand and ash are carried by wind, sometimes very far from the active crater, and are accumulated in a narrow belt zone on the lee side. In such a case, the thickness of accumulation on the ground and the size of ejecta decrease continuously according to the distance from the crater. The pattern of the distribution of fine ejecta in the present eruption is, however, quite different from the normal one. Moreover, Pueblo Nuevo and Tabacon, the center of accumulation of fine ejecta, were attacked by strong air blasts like air hammer just before heavy fall of fine ejecta. Therefore, it would be reasonable to assume that the distribution of fine ejecta in the present eruption is made not by wind transportation but by another dynamical mechanism.

It would be needless to say that a fragmental lava like lapilli or ash can not fly a long distance of 3 or 4 km with the initial velocity of

180 m/sec–200 m/sec for the reason that the air resistance acts seriously on smaller particle as is shown below;

$$R \equiv \frac{3k\rho'}{4\rho d},$$

where

k: resistance coefficient, 1.3 for lapilli, given by experiment,

ρ': air density,

ρ: bulk density of flying body,

d: diameter of flying body.

As is shown clearly in the above relation, the air resistance is inversely proportional to the diameter of the flying body if the densities of air and the flying body are constant.

If a large amount of fine ejecta from the lowest crater with the volcanic bombs of large size continued flying, not in a form of the independent particles but a giant single body with the similar initial velocity of nearly 200 m/sec, these fine ejecta would be carried rapidly in the incandescent state to Tabacon and Pueblo Nuevo villages. This is a probable assumption to explain the nuée ardente of Volcano Arenal. During the flight of an idealized body from the crater to the villages, it would be actually expanded by diffusion and by thermodynamical phenomena and, as the result, its bulk density would gradually decrease and the air resistance would seriously act. At the same time, therefore, if an expanded flying body lost not only the flying velocity toward the horizontal direction, but also the nature of an idealized body, the particles of fine ejecta would fall on the ground by gravity. It depends on the density concentration of the idealized body, its volume, its initial velocity, etc. whether the idealized body loses rapidly its flight motion as the inertia given at the crater or keeps it longer.

In the present case, the nuée ardente or the phenomenon caused by fine ejecta of high temperature on July 29 which attacked Pueblo Nuevo and Tabacon was not so destructive, and judging from the stratified layers of the fine ejecta at Pueblo Nuevo, it looked like the extremely heavy fall of lapilli and ash. It is indeed remarkable that a great number of big volcanic bombs and lava blocks fell on Tabacon and the east side of Pueblo Nuevo, and that the complete destruction of dwelling houses, cultivated land and trees at Tabacon originated not from accumulation of fine ejecta but from fall of an enormous number of bombs and detritus. Photographs in Figs. 17 and 18 show a lot of holes in the ground made by the fall of bombs and detritus at Tabacon and Pueblo Nuevo.

As described already, most of the present ejecta, including giant lava blocks, big bombs and fine ejecta, were distributed to the western direction of the new craters, because these craters were formed on the extremely steep slope of the west flank of Volcano Arenal, and, therefore, the western wall of the craters is markedly lower than the eastern one. In other words, the mouths of these craters are made on the western slope and the range of emission angle to the west side is remarkably bigger than that to the east side. On the contrary the emission angle to the east side of the craters is restricted within narrow limits near the vertical.

In general, the geographical distribution of ejecta is closely related to the topographical conditions of the crater, not only in the volume but also in the distance of their flight.

We must touch here on an estimation of temperature of ejecta. It was found that few of the wooden houses at Pueblo Nuevo were carbonized by the accumulation of fine ejecta. It seems that the temperature of fine ejecta and air temperature during the few hours of eruption on July 29 was in a range from 500°C to 300°C at Tabacon and Pueblo Nuevo. The temperature of the July 31 eruption at Quebrata Tabacon was a little higher than that of the July 29 eruption. On the other hand, the temperature of the aa lava stream which was ejected from the lowest crater after September 13 would be estimated a little higher than 1000°C, based on that of fresh lavas from basalt and andesite volcanoes in the world.

The nuée ardente of other volcanoes

In order to make the phenomena mentioned above a little more precise, it would be useful to compare the nuée ardente of Volcano Arenal with the historical nuées ardentes from other volcanoes with respect to their different types.

The nuées ardentes at the 1902 eruption of Mont Pelée mainly originated from collapses of a giant lava dome which was newly formed near the summit of the volcano. It is important to note that the locality connected with the extremely steep slope of the flank, on whose extending skirt St. Pierre, the capital of Martinique, was situated. On account of unexpected and rapid attack of the lava avalanche and fine ejecta of high temperature, more than ten thousand inhabitants of St. Pierre were killed and the whole city was completely destroyed in a few hours.

Since the lava dome was collapsed and broken into an immense number of lava blocks of various sizes, these lava blocks and fine ejecta in an incandescent state rushed down, rolling and sliding on the steep slope with a high velocity accelerated by gravity toward the foot of the mountain.

Villagers living in the western flank and skirt of Mt. Merapi, central Java, had the historic experience of damage by attack of lava avalanches and fine ejecta of high temperature. The lava avalanches of Mt. Merapi usually originated from the lava domes which were formed in the summit crater of a horse-shoe shape and were sometimes moved toward the west, sliding on the inclined floor of the crater. The summit crater opens, however, topographically to its west side and is connected directly with the steep slope and the deep valleys. After the lava dome shifted to the outlet, it was usual that the lava dome went down partly in the form of a lava stream and partly in the form of a lava avalanche. In general, the lava avalanche is more or less inseparable from the "nuée ardente" or shows the thermodynamical phenomena of incandescent lava fragment with vapour and gas.

In the 1939 Sakura-zima and the 1968 Mayon eruptions, the nuées ardentes were emitted from the upper flank in the former and from the summit in the latter. It could be remarked that the craters in the above both cases were located on and near the extremely steep slope.

The nuées ardentes of Mont Pelée and Mt. Merapi started not with large velocity, but with that given by the acceleration of gravity on the way of motion. However, the high velocity of the fine ejecta which attacked Pueblo Nuevo and Tabacon at the western foot of Volcano Arenal must be attributed to the initial motion of ejecta at the moment of eruption.

In this respect, the nuée ardente caused by the present eruption of Volcano Arenal is essentially different from that of Mont Pelée and Mt. Merapi.

4. Seismographic investigation of Volcano Arenal

For further research on the seismic activity of Volcano Arenal, the vertical and horizontal transducers were set; horizontal one at the station Fortuna about 6.3 km north-east, and vertical ones at the station Fortuna, at the station Volcano 3.3 km south-east and at the station Rio 6.5 km south-east, of the summit. We obtained seismograms of these transducers at three places on the same smoked paper at Fortuna by means of the displacement amplitude on the record. The seismic observation of the tripartite net (I) at those places was commenced on August 27 and 29 after the first eruption of Volcano Arenal and was over on September 29, while another seismometric tripartite net (II) was established at La Palma, 3.6 km NNE from the summit of Volcano

Arenal. After two weeks from August 27, it was moved to Fortuna. For the seismic observation by the tripartite net (II), we used a tape recorder with four channels.

An outline of the seismic activity of Volcano Arenal is shown in Table 1, indicating the result of seismic observation at the Fortuna and Volcano stations in a form of daily frequency, in which the earthquakes originating from the volcano and its adjacent area are classified into A and B types. The hypocenter of A type earthquake is more than 1.0 km in depth and that of B type earthquake less than 1.0 km in

Table 1. The daily frequency of earthquakes originating from Arenal

Date	Station Volcano		Station Fortuna		Remarks ( ); Total hours of no observation
	A-type	B-type	A-type	B-type	
1968					
August 26	—	—	0	0	(Stn. V.-All day long Stn. F-21h)
27	0	1	2	7	(Stn. V-16h)
28	2	3	1	2	
29	0	0	0	0	Volcanic tremor
30	0	12	0	4	
31	0	3	0	0	
September					
1	5	11	5	5	
2	0	10	0	8	
3	1	1	0	1	
4	0	6	0	6	
5	0	4	0	4	(14h)
6	—	—	—	—	(All day long)
7	1	0	1	0	(19h)
8	0	6	0	6	
9	0	3	0	3	
10	0	7	0	5	
11	0	3	0	2	
12	0	9	1	8	
13	2	2	2	1	
14	0	9	0	7	
15	2	16	3	4	
16	5	5	4	2	
17	0	13	0	4	
18	—	—	0	4	Explosion (Stn. V-All day long)
19	—	—			(All day long)
20	1	3	0	3	Volcanic tremor (St. V-20h)
21	0	0	0	0	
22	1	3	0	1	
23	0	6	0	3	Volcanic tremor
24	0	8	0	3	
25	2	10	2	5	
26	0	5	0	3	
27	0	12	0	1	
28	0	10	0	3	
29	0	18	0	3	(16h)

depth according to our classification of the volcanic earthquakes.

The geographical distribution of epicenters for the A type earthquakes is given in Fig. 5 on the basis of arrival times and $S-P$, and their hypocentral depth, judging from the nature of the earthquake motion in seismograms, is estimated in a range from 1 km to 10 km.

The locality of epicenter for the B type earthquakes is estimated by the amplitude distribution and the arrival times which were observed

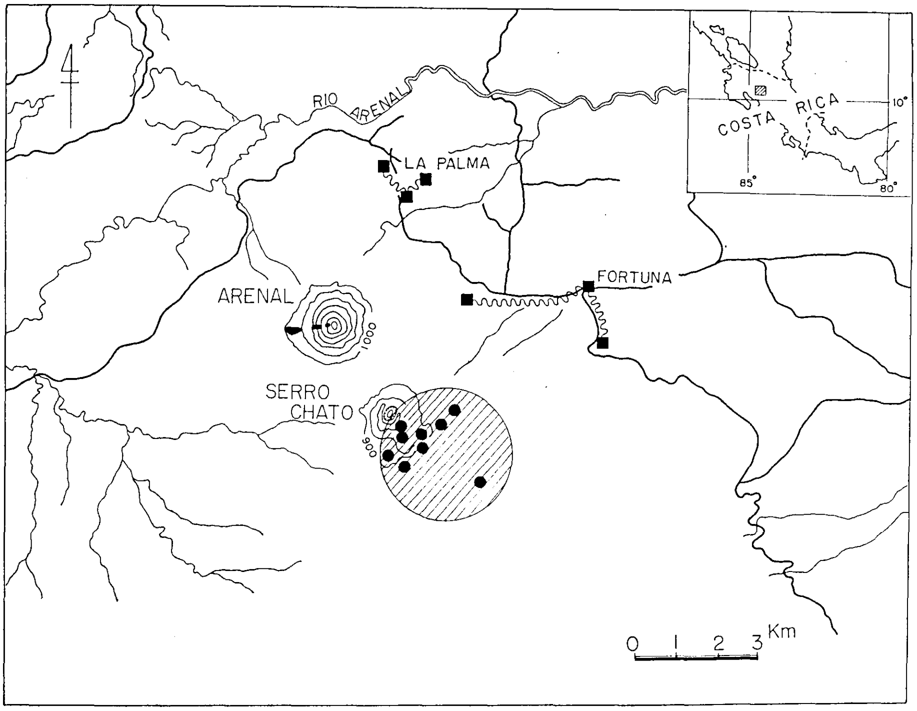

Fig. 5. Locality of the seismometrical nets and the epicentral area (hatched part).

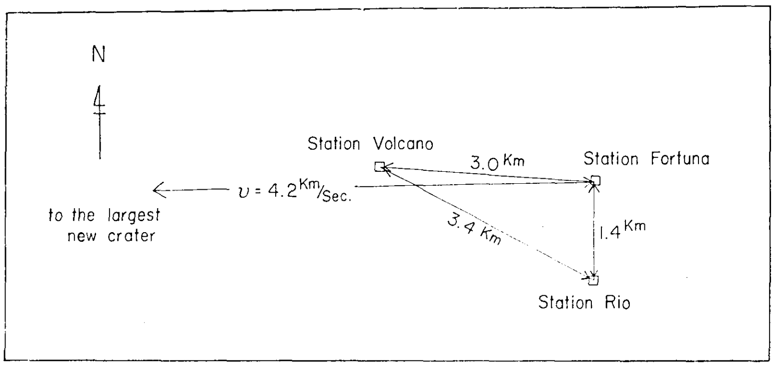

Fig. 6. Tripartite seismometrical net at Fortuna village.

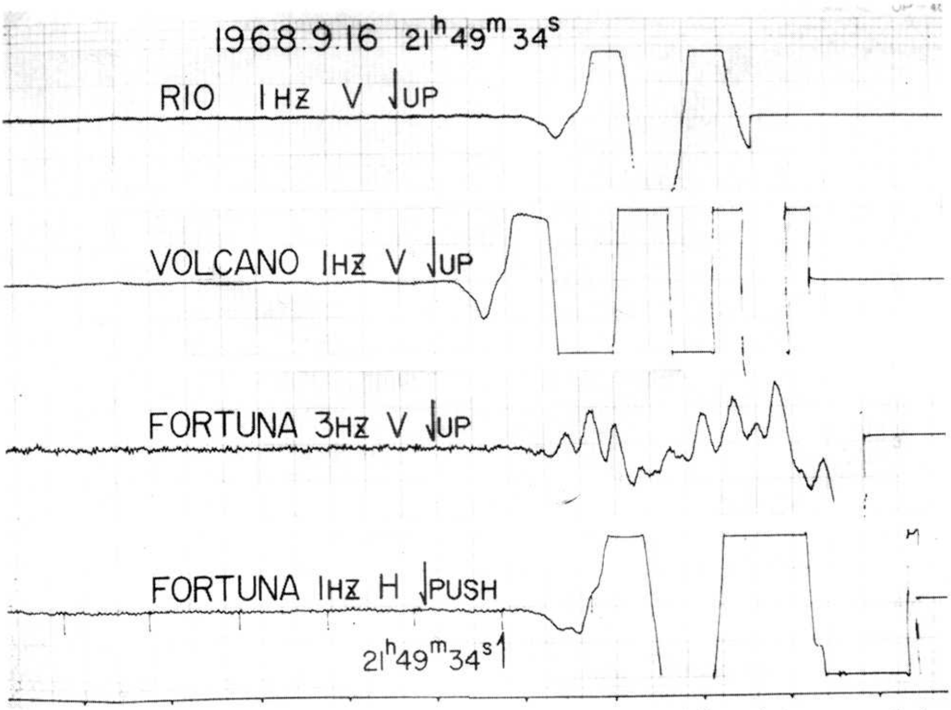

Fig. 7. The initial motion of the earthquake which was followed by an explosive eruption of the first or lowest crater.

by the tripartite net at the new craters, especially at the lowest crater.

During our seismometrical observation at Fortuna, we experienced several explosive eruptions. It was fortunate that we could catch on the tape recorder the earthquakes followed by the strong explosive eruption on September 13. The seismogram reproduced is shown in Fig. 7. According to our research on the earthquakes followed by explosive eruptions of volcanoes Asama and Sakura-zima, their epicenters are found just at the active crater and their initial motions are always "push" or "up" for all directions of the epicenter. In other words, this kind of earthquake is explained by a positive single source in the mechanism of production of seismic wave.

From precise examination of the seismogram, the arrival times of the initial motion at the three stations are given as follows;

Station	Arrival Time			Initial motion	Component
Volcano	21 h	49 m	33.48s	upward	vertical
Fortuna	"	"	34.07s	upward	vertical
"	"	"	34.20s	"	horizontal
"	"	"	34.23s	"	horizontal
Rio	"	"	34.26s	upward	vertical

The above mentioned earthquake also indicates "up" at the three places of the Fortuna net.

It was elucidated by the arrival times that the direction of the epicenter is quite coincident with that from the locality of our seismograph net to the lowest crater, where the explosive eruption took place. The apparent velocity of the initial wave or the P-wave showed 4.2km/sec.

5. Geothermal survey of Volcano Arenal

In order to make sure if any anomaly in the distribution of geothermal temperature would be found on and around Volcano Arenal, we made a series of measurements of the geothermal temperature at 0.7 m below the earth's surface in the various altitudes of the volcano. At the same time the continuous observation of geothermal temperature at 1.0 m and 0.5 m below the earth's surface and the measurement of air temperature were carried out at Fortuna village during the period from August 31 to September 24.

According to the result of this continuous observation the geothermal temperatures at 1.0 m and 0.5 m below the earth's surface were affected by the diurnal variation of air temperature in a range of less than $\pm 1.0°C$ as the maximum deviation from the diurnal mean value of air temperature. On the other hand, the annual variation of air temperature in Costa Rica is in a range of less than $\pm 0.9°C$ as the maximum deviation from the annual mean value of air temperature, according to the results of the observation at the El Coco and Centro Weather Stations.

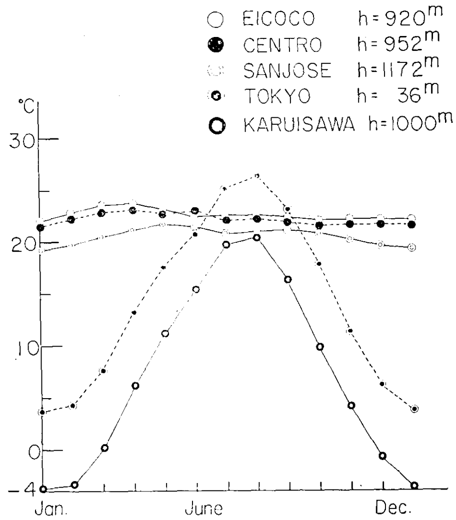

Fig. 8. Annual variation of air temperature in Costa Rica and Japan.

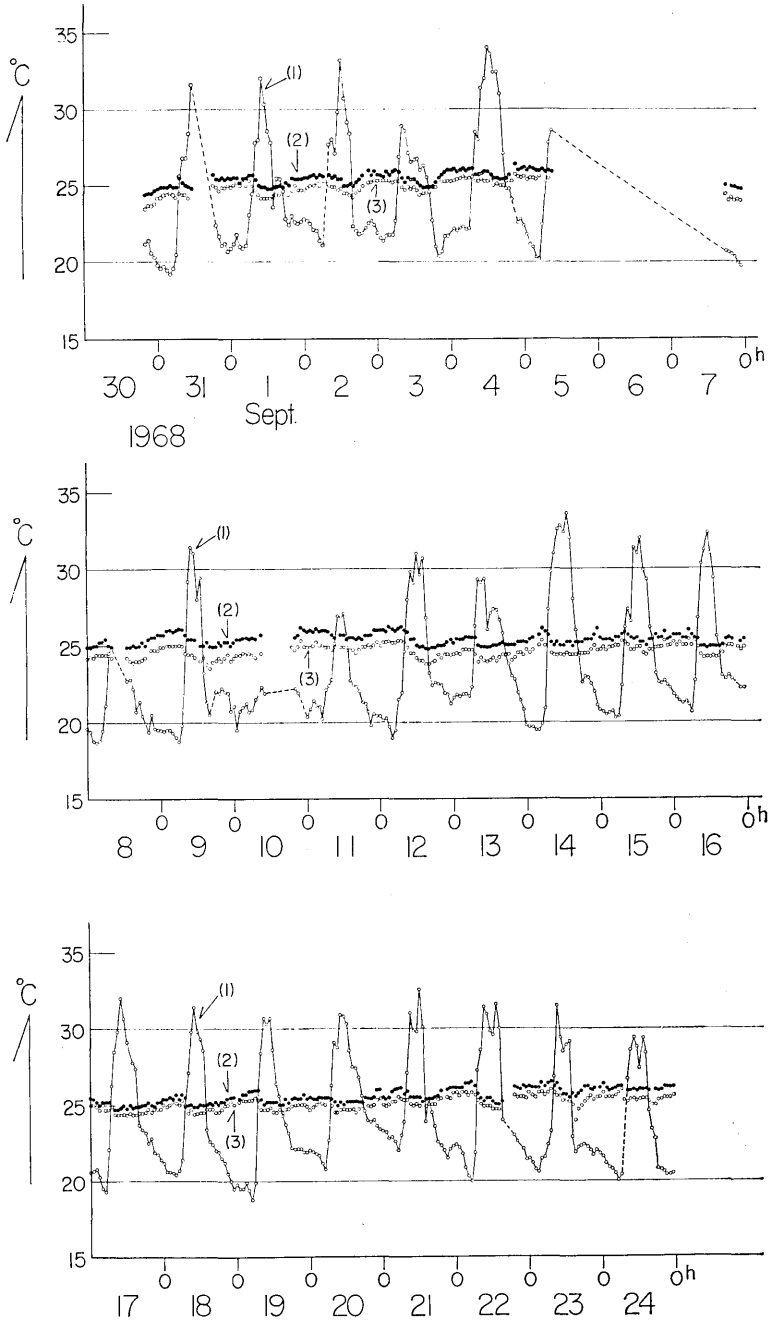

Fig. 9. Result of continuous observation of air temperature and geothermal temperature at 1 m and 0.5 m below the earth's surface at Fortuna village: (1) air temperature, (2) geothermal temperature at the depth of 1 m, (3) geothermal temperature at the depth of 0.5 m.

Therefore, the geothermal temperatures observed at 0.7 m below the earth's surface at Volcano Arenal must indicate the annual mean value of the air temperature at respective altitudes with the error of less than 1.0°C, unless there is anomaly of the geothermal temperature.

Table 2. Geothermal temperature measurement on Volcano Arenal

Date	Time	Measurement No.	Observed geothermal temp. (To) °C	Altitude m	Calculated temp. (Tc) °C	Anomaly (To-Tc) °C	Remarks
1968	h m						
Sept. 9	14 : 10	1	24.0	300	25.3	− 1.3	
"	14 : 30	2	25.0	360	24.9	+ 0.1	
"	14 : 50	3	25.5	350	24.9	+ 0.6	
"	15 : 10	4	24.0	420	24.5	− 0.5	
"	15 : 25	5	25.5	380	24.7	+ 0.8	
"	15 : 50	6	23.5	400	24.6	− 1.1	
"	16 : 30	7	23.5	475	24.1	− 0.6	
"	17 : 05	8	23.5	500	23.9	− 0.4	
Sept. 10	13 : 05	9	23.0	560	23.5	− 0.5	
"	14 : 00	10	24.0	560	23.5	+ 0.5	*
"	14 : 10	11	23.0	560	23.5	− 0.5	
"	14 : 30	12	23.5	600	23.2	+ 0.3	
"	15 : 15	13	23.5	560	23.5	0	
Sept. 11	11 : 30	14	23.0	560	23.5	− 0.5	
"	12 : 40	15	25.0	600	23.2	+ 1.8	
"	13 : 40	16	24.5	580	23.4	+ 1.1	
"	14 : 05	17	23.0	540	23.6	− 0.6	
Sept. 13	15 : 00	18	26.0	1050	20.2	+ 5.8	
"	15 : 15	19	21.0	1060	20.2	+ 0.8	
"	16 : 10	20	63.0	950	20.9	+42.1	**
"	16 : 20	21	80.0	900	21.2	+58.8	**
"	16 : 40	22	22.3	800	21.9	+ 0.4	
"	16 : 50	23	23.5	720	22.4	+ 1.1	
Sept. 16	10 : 00	24	26.5	100	26.6	− 0.1	
"	10 : 15	25	26.3	80	26.7	− 0.4	
"	10 : 40	26	25.8	180	26.1	− 0.3	
Sept. 9	13 : 30	27	26.0	250	25.6	+ 0.4	Stn. Rio

Remarks: * The place where a jeep was burnt.
** The thick accumulation of fine ejecta on the lowest crater.

The measured values of geothermal temperature are listed in Table 2 which also shows the altitudes of the respective places. The localities of measurement are shown on the map in Fig. 11.

For examining the anomaly of the geothermal temperature from the measurement, it is necessary to investigate the relation between the measured geothermal temperature and the altitude where we measured. Therefore, the corelation between the two values is represented in Fig. 10 and is expressed by the following formula;

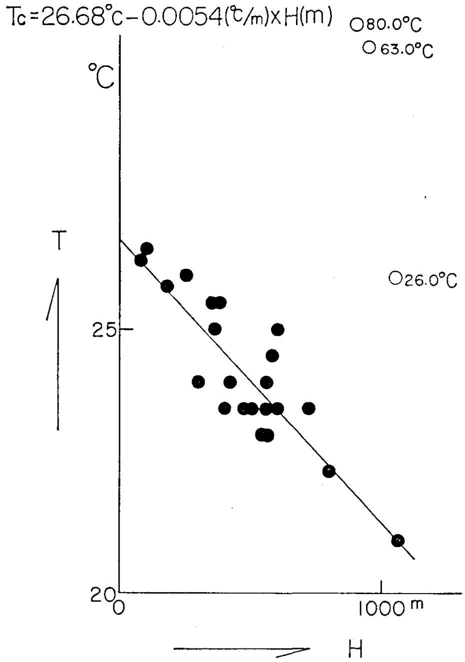

Fig. 10. Relations between geothermal temperature at the depth of 0.7 m and the altitude of the measured place in Volcano Arenal, Costa Rica.

$$T_C = 26.68°C - 0.0054(°C/m) \times H(m)$$

In the above formula, the rate of decrease of geothermal temperature relative to altitude shows 0.54°C for every 100 m which agrees almost with that of air temperature (0.65°C) according to the altitude. Consequently it is reasonable to define the geothermal anomaly by the difference between the measured value (T_0) at a place and that (Tc) given by the above formula corresponding to its altitude. The difference defined is also given in Table 2.

The differences between two kinds of temperature (T_0 and Tc) are less than $\pm 1.5°C$ except at three places (Nos. 18, 20 and 21). The geothermal temperatures at the three places are exceedingly higher than the normal value expected from the above formula. Since the above-mentioned three places and their adjacent area were thickly covered by new fine ejecta, it seems that the ejecta and the original earth's surface just under the ejecta were still at a high temperature at the time of our measurement.

It would be, therefore, natural to conclude that the anomalously high temperature at the places mentioned above should not be caused by the heat inside the volcano and that no anomaly of the geothermal

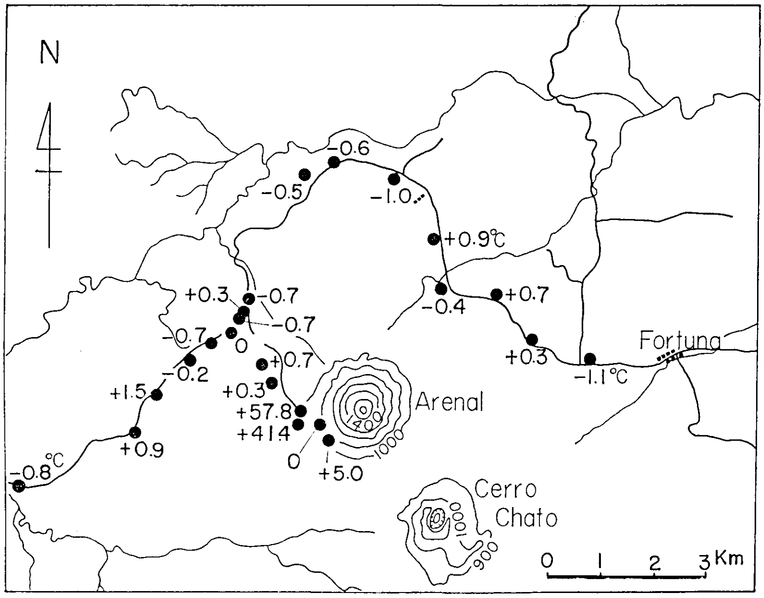

Fig. 11. The anomalous distribution of the geothermal temperature in Volcano Arenal.

temperature would appear at Volcano Arenal as far as the area of our geothrmal survey was concerned.

6. Conclusion

The catastrophic eruption of Volcano Arenal on July 29 and 31, 1968, attracted the attention of all the volcanologists in the world because Volcano Arenal had no record of historical eruption up to July 29, and the nuées ardentes in the eruption killed at least 78 persons at the western skirt of the mountain.

We made field investigation of the devastated area with respect to the geographical distribution of ejecta and the locality of the newly formed craters. On the basis of the result, we researched the initial velocity of ejecta, the kinetic energy of the present eruption and the mechanism of production of the nuée ardente.

On the other hand, the seismic observation at Fortuna was carried out in order to have the information relative to the seismic activity of the volcano and its adjacent area.

The geothermal measurement at 29 places on the volcano was taken for investigation of the geothermal feature of Volcano Arenal but no anomaly of the geothermal temperature was found as far as our survey was concerned.

Since tropical regions such as Costa Rica, Indonesia etc. usually have a mild climate throughout the year on the high mountains, many inhabitants live near active craters. In order to prevent them from suffering disaster by the eruption, it is recommended that special precautions should be taken by building their houses and other constructions at places quite far from active craters and active fissures. In addition, it is strongly recommended that a volcano observatory at Arenal which is equipped with high sensitive seismographs and other geophysical instruments should be established as a permanent project in order to have continuous information with respect to volcanic and seismic activities.

In concluding we wish to express our sincere thanks to Mr. F. Lizano Porras, the director of Defenza Civil, and Mr. R. Sáenz R., the chief of Section of Seismology and Volcanology, for their kindness and thoughtfulness in affording facilities for us in our survey at Volcano Arenal. Our hearty thanks should also be extended to the Japanese Embassy at San Jose and the Overseas Technical Cooperation Agency for their helpful guidance during our stay in Costa Rica.

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34. アレナル火山(コスタリカ)の1968年の噴火

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1968年7月29日，中米コスタリカ国の西北部に位置するアレナル火山は大噴火し，2日後の31日にも激しい噴火が発生した．そのため西山麓のタバコン，プエブロ・ヌエボの2部落は全滅し，少なくとも78名の生命が失なわれた．いわゆる熱雲による被害が主であつたと報告された．

上記火山の地球物理学的調査と，でき得れば今後の活動についての見解を，コスタリカ及びわが外務省より要望され，地震計類等，若干の測定計器を輸送し，8月中旬より約1ヶ月半に亘つて現地調査を行なつた．調査結果の概要は次のごときものである．

(1) アレナル火山の今回の噴火は同火山の噴火記録上最初のものであつた．

(2) アレナル火山は地形上規則正しい円錐状火山で，中腹以上は極めて急斜面を持つている．この斜面上の山腹より西方にほぼ1線上の3つの新しい火口が形成され，それより噴火が起こつた．最も低い位置に生じた火口は最も大きく，噴出の大部分はこの火口よりのものであつた．9月14日後，aa 型の溶岩流が上記の火口より流出した．

(3) 大きい溶岩塊，火山弾の分布，噴出物の体積等の調査から求めた器械的エネルギーは約 10^{22} エルグ程度であつた．

(4) 火山礫，火山砂，火山灰等の小噴出の堆積，分布状態，家屋の被害状況から見て熱雲の運動について考えてみた．かつメラピイ，プレ火山等の熱雲と比較した．

(5) アレナル火山の北東部及び東部山麓ラパルマ村及びフォルツナ村において地震観測を行なつた．著しい地震活動は8月下旬から1ヶ月の期間には発生しなかつた．しかし小さい地震はアレナル火山の南東近傍にあるセロシャトウ火山の麓にやや深い A 型の地震が発生し，新火口近くからは火山性脈動及び B 型地震が現われた．

(6) アレナル火山地表下の地中温度分布を調査した．新火口附近の新噴出物が厚く堆積している地点以外では異常の地中温度を示す所は測定の範囲内では存在しなかつた．

(7) 7月29日の最初の噴火が発生する前の数日の間に，山麓のプエブロヌエボ，タバコン，フォルツナ等の村々で多数の地震を感じたことが，住民によつて報ぜられている．つまり有感地震が噴火前にかなり発生した事は明らかである．

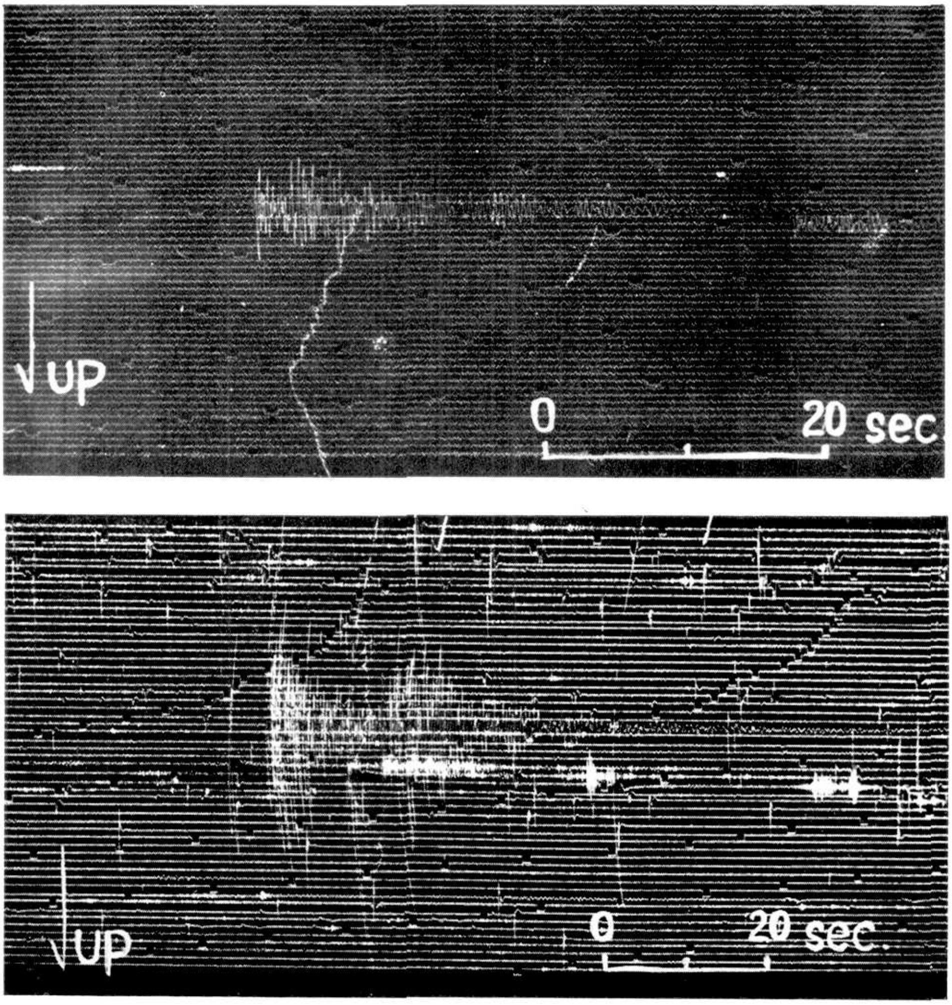

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Fig. 12. The seismograms of earthquakes originating from the south-eastern foot of Volcanoes Arenal and Cerro Chato.

Fig. 13. Volcano Arenal and the newly formed craters seen from the north-eastern foot of the volcano.

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Fig. 14. The temporary seismometrical station at Fortuna village.

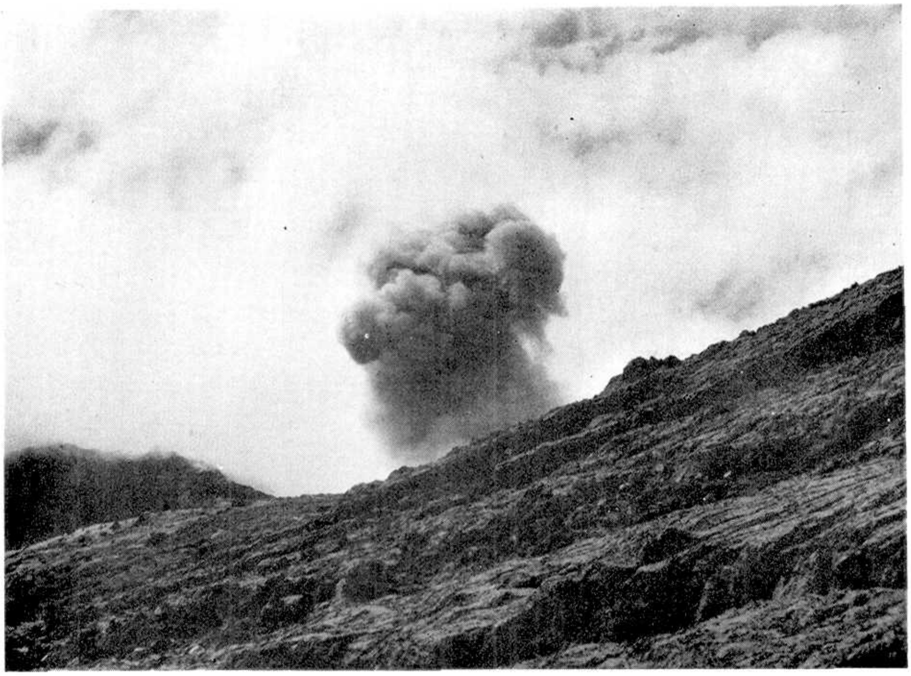

Fig. 15. Small eruption from the lowest crater.

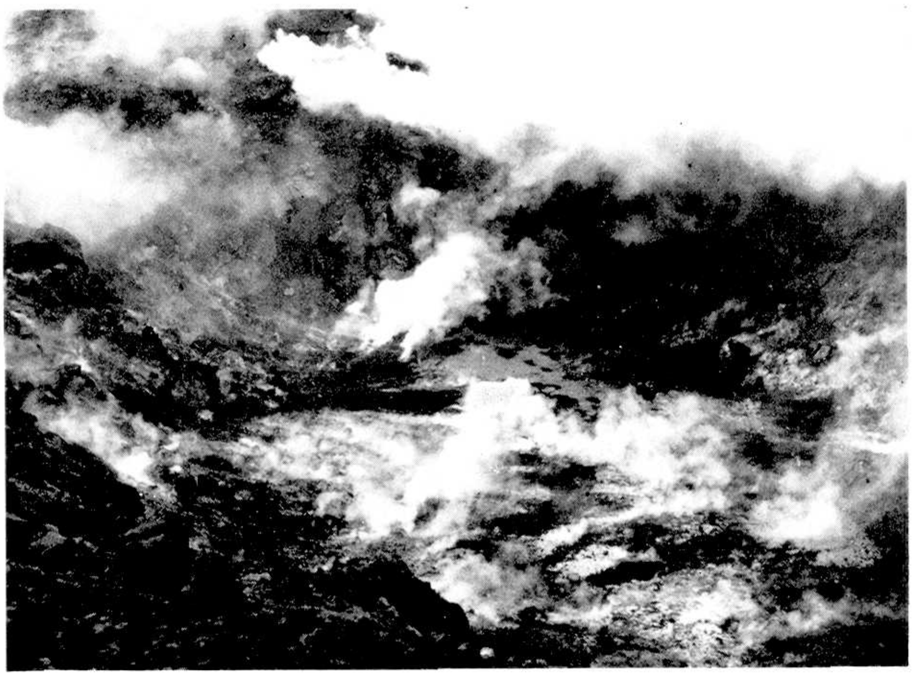

Fig. 16. The floor of the lowest crater.

Fig. 17. The holes on the ground made by the fall of lava blocks and bombs at Pueblo Nuevo.

Fig. 18. The holes on the ground made by the fall of lava blocks and bombs at Pueblo Nuevo.

Fig. 19. The newly accumulated fine ejecta at Pueblo Nuevo.

Fig. 20. The newly accumulated fine ejecta at Pueblo Nuevo.

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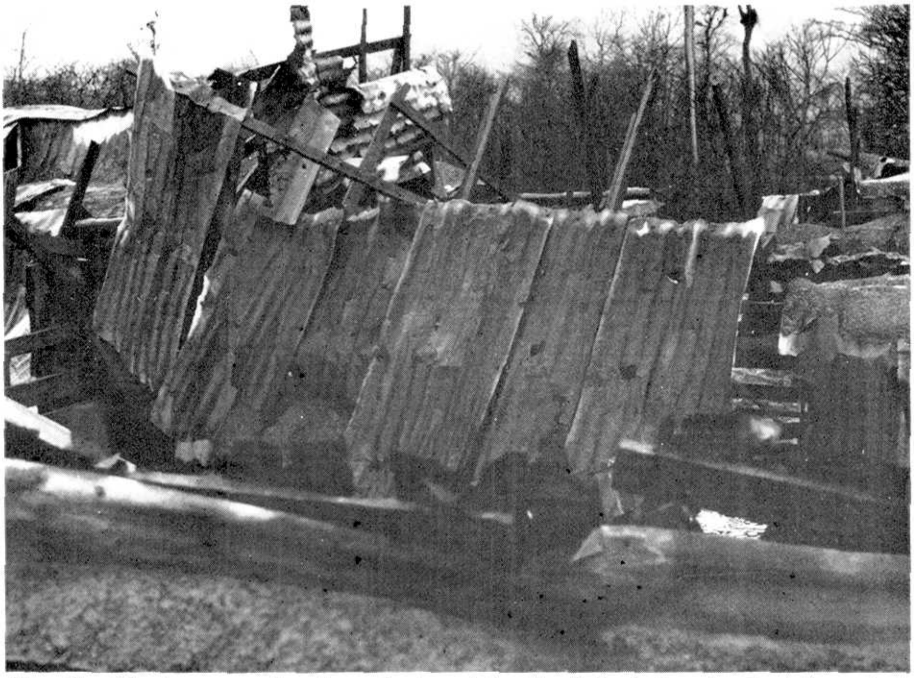

Fig. 21. The houses and cottage destroyed by the fall of the abundant fine ejecta of July 29 at Pueblo Nuevo.

Fig. 22. The houses and cottages destroyed by the fall of the abundant fine ejecta of July 29 at Pueblo Nuevo.