An Investigation of Earth Currents on the Volcano Aso

Part I. The Potential Difference of the Upward Earth-current flowing toward the top of a Volcano

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Abstract

It is a well known fact that there is always a certain definite ascending current along an inclined earth surface. The writer has measured the distributions of the potential gradient of the earth current near the mountain tops of several volcanic cones, and arrived at the conclusion that the ascending current of a cinder cone is mainly due to the streaming potential caused by the soil pressure difference.

I. Introduction

It is a well known fact that there is a certain ascending electric current on the surface of a slope of the earth.

The writer measured the distributions of the potential gradient of the earth current on the two cinder cones of Kome-tsuka and Ôgi-yama which are extinct volcanoes. He also made similar measurements on other volcanic cones, such as the Ôjo-dake and the Yomine. Having investigated the distributions of the potential gradient of the earth current, he found that;

1). In the case of cinder cones, they were caused by the pressure of the earth.

2). In the case of conides, the distributions of the potential gradient caused by the pressure of the earth were disturbed by the lava flow.

II. The Instrument and Method of Measurements

§ 1. *Potentiometer.* P. P. P. type portable potentiometer, manufactured by the Shimazu Manufacturing Co., is used; its whole resistance is 950 ohms, sensibility is one m. v. And by means of this potentiometer it is possible to measure from 0.1 m. v. to 1.4 volts.

§ 2. *Pole Pieces.* A Cu pole 6 mm × 20 cm is cut equally in two, one of these pieces being used as positive pole and the other as negative. Each of these two pieces of the Cu pole is inserted into an unglazed porcelain pot (2 cm × 15 cm) which has been filled with pow-

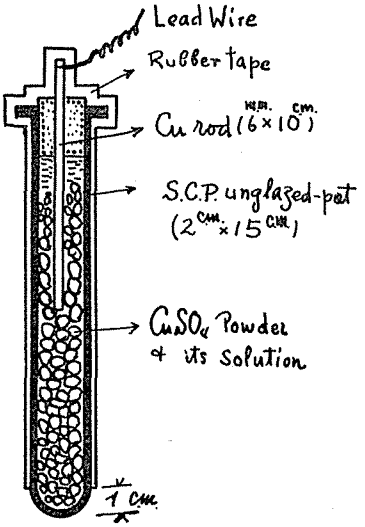

Fig. 1. Section of a Pole Piece.

dered chemically pure $CuSO_4$ crystal and water. Then these pots are sealed with rubber corks. They should not be filled up to the lower part of the cork with $CuSO_4$ powder, but space of several millimeters must be left for water only so that the content of the pot may be mingled.

The outside of the pot is taped with rubber tape that it may be well insulated and also kept warm, but the lower one centimeter of it must be left untaped so that that portion may make contact with the soil. When these pots are not in use, the portion of contact should be wet with a wet sponge. A set which the writer is now using have the fixed voltage of 1.8 m. v. This may be due to the impurity of the content of the unglazed porcelain. In this field measurement, this fixed voltage has shown no change.

§ 3. *Manipulation.* The potentiometer set described is very convenient to handle so that we have been able to observe the main current promptly at any time desired during the measurement. The distance between the poles is 50 meters and the poles are connected with rubber cord (s. w. g. 20) 60 meters in length. After the reading is made, the poles are exchanged and the reading is made again. After taking the mean value of the two, the fixed voltage of the pole piece is subtracted.

In the readings 0.1 m. v. has been adopted, but with the consideration of several questions at the time of the field work, it is desired to adopt up to 10 m. v. The pole pieces are inserted into the soil for 20 cm.

III. Results of Measurements

§ 4. *The Cinder Cone "Kome-tsuka".* There is a cinder cone 954 meters above the sea level at the foot of the north-west of Kishima-dake, one of Aso's five central cones. It is called Kome-tsuka (Fig. 2A). The whole cone is covered with grass. It has the shape of a truncated cone and rises about 50 meters above the level ground. The crater at the top of the cone is about 10 meters deep and 100 meters in diameter. We took the middle of the crater as the center (origin), covering the whole hill with observation points forming a net whose sides are 50 meters long, and measured the direction of the potential gradient of the earth current. We found that the currents gather on the north top of the crater rim as is shown in Fig. 2 C. It agrees with the report of J. E. Burbank that " Earth currents are known to flow from all sides up a mountain toward the top ".*

It was found that Kome-tsuka has an almost homogeneous structure under the part of the mountain we surveyed. This will be shown later in the present paper. At the time of the survey, we found no considerable difference in the temperature between the top and the foot of the mountain (Table 1).

Table 1. Temperatures at the Kome-tsuka. (1936 June 7th)

Center	22.2°C
North foot	23.0°C
West foot	22.6°C
South foot	23.0°C
East foot	22.3°C

(each at the surface)

The equation of the profile of this volcano is calculated as $y = 11e^{0.01x}$ from the observation data (Table 2). In the equation the origin is at the top of the cone, x means the horizontal distance, and y means the vertical downward distance from the origin.

Table 2. Observed difference of the points.
(Kome-tsuka, 1936 June 7th)

Points	$(O, O;\ O, E_1)$	$(O, E_1;\ O, E_2)$	$(O, E_2;\ O, E_3)$
	←	→	→
Height Diff.	15.95^{m}	16.25	25.60
Potent. Diff.	4.8^{mv}	74.8	81.7
	←	←	←
Points	$(O, O;\ O, N_1)$	$(O, N_1;\ O, N_2)$	$(O, N_2;\ O, N_3)$
	←	→	→
Height Diff.	11.90^{m}	22.05	25.10
Potent. Diff.	42.7^{mv}	38.3	34.0
	→	←	←
Points	$(O, O;\ O, W_1)$	$(O, W_1;\ O, W_2)$	$(O, W_2;\ O, W_3)$
	←	→	→
Height Diff.	12.50^{m}	22.45	27.60
Potent. Diff.	36.9^{mV}	98.3	46.8
	→	←	←

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* J. E. Burbank :– Earth-currents and a proposed method for their investigation. Terr. Magn. and Atmos. Electr. Vol. 10. 1905. pp. 23–49.

Points	(O, O; O, S$_1$)	(O, S$_1$; O, S$_1$)	(O, S$_2$; O, S$_3$)
	$\longleftarrow$	$\longrightarrow$	$\longrightarrow$
Height Diff.	6.60^{m}	21.15	26.40
Potent. Diff.	19.0^{mv}	101.4	46.3
	$\longleftarrow$	$\longleftarrow$	$\longleftarrow$
Points	(O, N$_1$; E$_1$. N$_1$)	(E$_1$, N$_1$; E$_2$, N$_1$)	(E$_2$, N$_1$; E$_3$, N$_1$)
	$\longrightarrow$	$\longrightarrow$	$\longrightarrow$
Height Diff.	1.95^{m}	17.75	24.85
Potent. Diff.	15.0^{mv}	77.1	71.0
	$\longleftarrow$	$\longleftarrow$	$\longleftarrow$
Points	(O, N$_1$; W$_1$, N$_1$)	(W$_1$, N$_1$; W$_2$, N$_1$)	(W$_2$, N$_1$; W$_3$, N$_2$)
	$\longrightarrow$	$\longrightarrow$	$\longrightarrow$
Height Diff.	5.45^{m}	17.75	24.85
Potent. Diff.	38.8^{mv}	49.0	56.0
	$\longrightarrow$	$\longleftarrow$	$\longleftarrow$
Points	(O, S$_1$; E$_1$, S$_1$)	(E$_1$, S$_1$; E$_2$, S$_1$)	(E$_2$, S$_1$; E$_3$, S$_1$)
	$\longrightarrow$	$\longrightarrow$	$\longrightarrow$
Height Diff.	3.05^{m}	17.40	21.20
Potent. Diff.	41.5^{mv}	68.8	52.3
	$\longleftarrow$	$\longleftarrow$	$\longleftarrow$
Points	(O, S$_1$; W$_1$, S$_1$)	(W$_1$, S$_1$; W$_2$, S$_1$)	(W$_2$, S$_1$; W$_3$, S$_1$)
	$\longrightarrow$	$\longrightarrow$	$\longrightarrow$
Height Diff.	6.00^{m}	22.55	26.10
Potent. Diff.	48.1^{mv}	68.0	31.5
	$\longleftarrow$	$\longleftarrow$	$\longleftarrow$
Points	(O, E$_1$; E$_1$, N$_1$)	(E$_1$, N$_1$; E$_1$, N$_2$)	(E$_1$, N$_2$; E$_1$. N$_3$)
	$\longrightarrow$	$\longrightarrow$	$\longrightarrow$
Height Diff.	5.50^{m}	16.18	23.75
Potent. Diff.	3.5^{mv}	28.7	23.5
	$\longrightarrow$	$\longleftarrow$	$\longleftarrow$
Points	(O, W$_1$; W$_1$, N$_1$)	(W$_1$, N$_1$; W$_1$, N$_2$)	(W$_1$, N$_2$; W$_1$, N$_3$)
	$\longrightarrow$	$\longrightarrow$	$\longrightarrow$
Height Diff.	7.25^{m}	20.90	25.80
Potent. Diff.	24.0^{mv}	33.7	24.4
	$\longrightarrow$	$\longleftarrow$	$\longleftarrow$
Points	(O, E$_1$; E$_1$, S$_2$)	(E$_1$, S$_1$; E$_1$, S$_2$)	(E$_1$, S$_2$; E$_1$, S$_3$)
	$\longrightarrow$	$\longrightarrow$	$\longrightarrow$
Height Diff.	11.45^{m}	25.20	27.50
Potent. Diff.	65.0^{mv}	78.0	50.5
	$\longleftarrow$	$\longleftarrow$	$\longleftarrow$
Points	(O, W$_1$; W$_1$, S$_1$)	(W$_1$, S$_1$; S$_1$, W$_2$)	(W$_1$, S$_2$; W$_1$, S$_3$)
	$\longrightarrow$	$\longrightarrow$	$\longrightarrow$
Height Diff.	13.00^{m}	23.00	25.50
Potent. Diff.	107.3^{mv}	70.0	33.9
	$\longleftarrow$	$\longleftarrow$	$\longleftarrow$

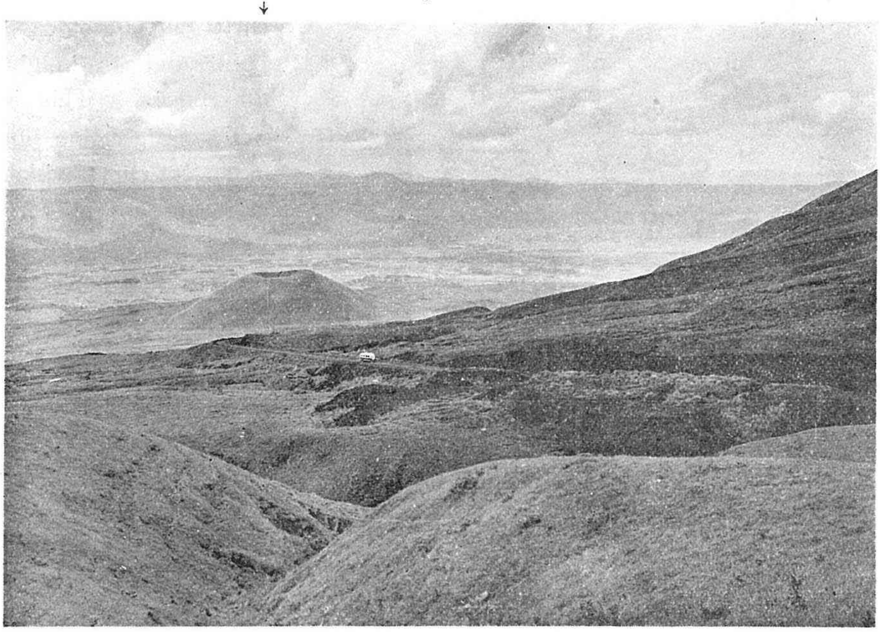
Points	(O, O ; 1)	(1 ; 2)	(2 ; 3)
	$\longrightarrow$	$\longrightarrow$	$\longrightarrow$
Mean Height Diff.	3.74^{m}	20.17^{m}	25.16^{m}
	$\longleftarrow$	$\longleftarrow$	$\longleftarrow$
Mean Potent. Diff.	27.2^{mv}	62.6^{mv}	44.4^{mv}

From the above data we can find the co-ordinates of the points as:—

Points	(top),	(1),	(2),	(3).
x, y	(0, 0),	(50, 4),	(96, 24),	(139, 49).

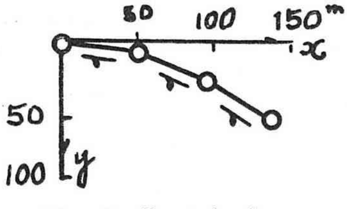
The graph in Fig. 2B shows the mean values of measurement of po-

Fig. 2 A

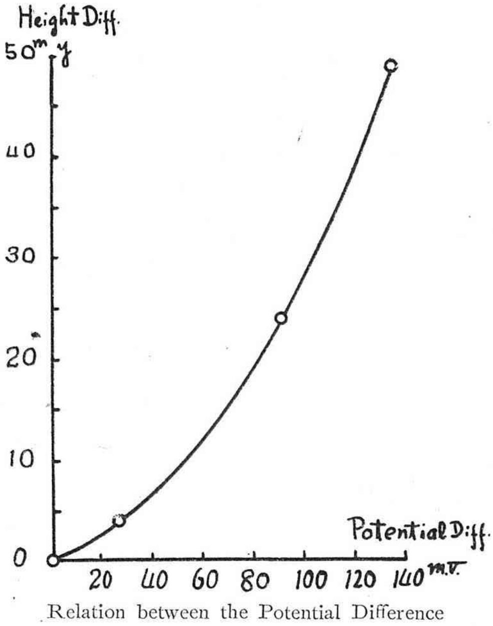


Kome-tsuka (The View from South).

Fig. 2 B

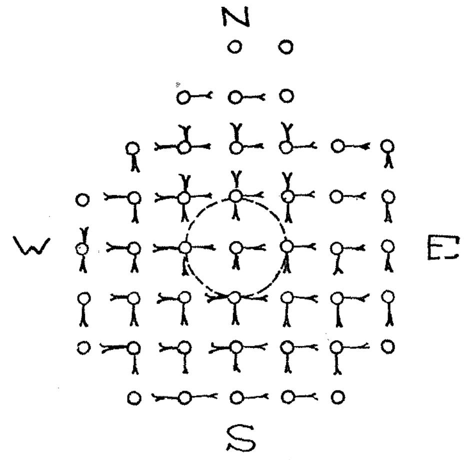


Mean Profile of the Cone.
(Kome-tsuka)

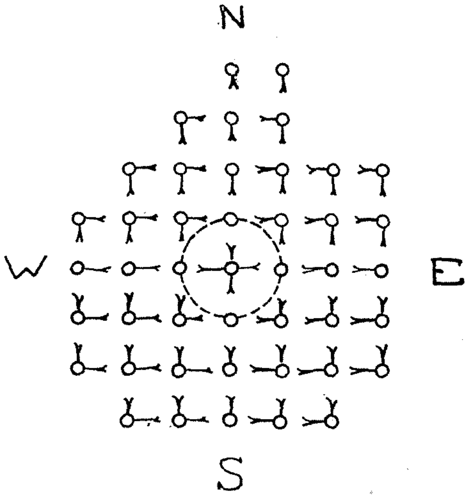


Relation between the Potential Difference and the Height Difference. (Kome-tsuka)

Fig. 2 C



Height Differences of the Points.



Potential Differences of them.

tential gradient of the earth current at each point and its height differences. This is not a straight line, but a perfect curve which is rather concave toward the y axis (the height difference axis).

§ 5. *The Cinder Cone "Ôgi-yama".* The Ôgi-yama volcano, 792.0 meters above the sea, is a cinder cone whose skirt extends toward Beppu Bay. The east and west sides are somewhat flat, and the slope develops on the north and south sides. The differences of the height and potential differences measured along the south-north line are indicated in Table 3.

This is illustrated in Fig. 3.

Table 3. Data at Ôgi-yama.
(1936 Aug. 17th.)

Points (North)	(Top ; 1)	(1 ; 2)	(2 ; 3)	(3 ; 4)	(4 ; 5)	(5 ; 6)	(6 ; 7)
Height Diff.	10.57$^{\mathrm{m}}$ →	19.69 →	20.02 →	20.89 →	19.37 →	20.57 →	19.15 →
Potential Diff.	11.19$^{\mathrm{mv}}$ →	50.7 →	2.0 →	44.5 ←	123.4 ←	108.9 ←	128.8 ←

Points (South)	(Top ; 1)	(1 ; 2)	(2 ; 3)	(3 ; 4)	(4 ; 5)	(5 ; 6)
Height Diff.	→ 21.32$^{\text{m}}$	→ 23.50	→ 26.19	→ 23.16	→ 16.68	→ 19.30
Potential Diff.	← 197.0$^{\text{mv}}$	← 203.0	← 127.0	← 148.2	← 226.0	← 115.5

Points	(Top ; 1)	(1 ; 2)	(2 ; 3)	(3 ; 4)	(4 ; 5)	(5 ; 6)	(6 ; 7)
Mean H. D.	→ 15.95$^{\text{m}}$	→ 21.60	→ 23.11	→ 22.03	→ 18.03	→ 19.94	→ 19.15
Mean P. D.	42.6$^{\text{mv}}$ ←	76.2 ←	62.5 ←	96.4 ←	174.7 ←	112.2 ←	128.8 ←

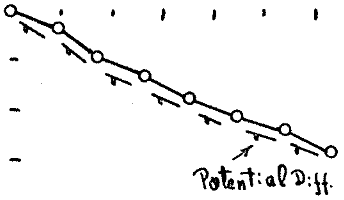


Fig. 3. Profile of the Cone. (Ôgi-yama)

§ 6. *The Toloide "Yomine"*. This is the oldest volcano, 913 meters above the sea, among the group of the volcanic central cones of Mt. Aso; its slopes extend to the east, south, and the west sides of the mountain, while the northern slope faces the blasted crater of the Jigoku and it is covered with the lava of the Eboshi-dake. The northern slope is planted with trees, while three other sides are covered with grass.

The relation of the height and the potential differences measured along EW line is shown in the table 4 and Fig. 4.

Table 4. Data at Yomine.
(1936 Aug. 11th.)

Points	(Top-1)	(1-2)	(2-3)	(3-4)	(4-5)	(5-6)	(6-7)	(7-8)	……East
H. D.	→ 4.03$^{\text{m}}$	→ 8.91	→ 11.02	→ 11.08	→ 12.21	→ 15.02	→ 29.20	→ 26.45	
P. D.	← 17.3$^{\text{mv}}$	← 42.4	← 15.8	← 12.3	← 3.3	→ 0.3	→ 9.0	→ 3.0	
H. D.	→ 3.88$^{\text{m}}$	→ 4.55	→ 6.62	→ 15.55	→ 23.74	→ 26.00	→ 26.82	→ 26.50	……West
P. D.	→ 35.0$^{\text{mv}}$	→ 10.0	→ 14.0	→ 9.6	← 26.5	← 27.5	← 37.6	← 50.5	
H. D.	→ 18.75$^{\text{m}}$	→ 20.60	→ 20.10	→ 28.95	→ 20.30	→ 28.70	→ 20.70	→ 31.65	……South
P. D.	← 26.7$^{\text{mv}}$	← 8.4	→ 3.0	→ 11.0	→ 6.4	→ 9.0	→ 2.0	→ 44.5	

	The Mean Values in EW line								
H. D.	→ 3.96^{m}	→ 6.73	→ 8.82	→ 13.32	→ 17.98	→ 20.51	→ 28.01	→ 26.48	
P. D.	→ 8.9^{mv}	← 16.2	← 0.9	← 1.9	← 11.6	← 13.6	← 14.3	← 23.8	

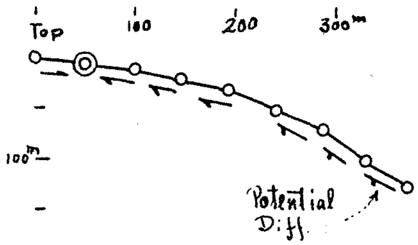


Fig. 4. Profile of the Cone. (Yomine)

And the graph of the measurement above mentioned is entirely different, taking the measurement southward from the triangle point into consideration, from those of Kome-tsuka and Ôgi-yama, and here we find there are potential differences which face downward from the top. This seems to me to show that there is a lava flow under the ground. If we examine the graph on the differences of height and potential, it is noticeable that the direction of the potential gradients from the foot and the top comes together about 50 meters from the top. This may be the effect of the under ground lava flow (Aug. Hype. andesite) which exists near that level.

§ 7. *The Conide Ôjo-dake.* Ôjo-dake is one of the Aso central cones and it is the same mountain that is recorded as Kishima-dake in the history of Higo-Kokushi and also in the report No. 33 of the Japan Earthquake Inv. Committee. Its height is 1238.1 meters according to our Land Survey map. There are three craters on this mountain. The northern rim of the western crater and its northern slope develop on the lave flow which covers the western half of Aso-dani. This

Table 5. Data at the Conide Ôjo-dake.
(1936 Sept. 1st.)

Points (North)	(Δ-1)	(1-2)	(2-3)	(3-4)	(4-5)	(5-6)	(6-7)	(7-8)	(8-9)	(9-10)	(10-11)	(11-12)	(12-13)	(13-14)	(14-15)	(15-16)	(16-17)
H. D.	→ 15.15^{m}	→ 21.00	→ 23.75	→ 47.60		→ 24.55	→ 18.70	→ 20.60	→ 23.85	→ 19.70	→ 29.70^{m}	→ 19.95	→ 19.20	→ 11.50	→ 8.25	→ 10.50	→ 15.20
P. D.	→ 78.5^{mv}	→ 50.0	→ 54.5	→ 46.5	→ 10.9	← 5.1	← 18.8	← 9.6	→ 29.0	→ 23.5	→ 6.0^{mv}	← 13.0	← 41.0	← 32.5	← 17.0	← 12.5	← 3.0

volcano commands a very beautiful scene of pasture land, and it is determined as the conide.

As the distribution of the potential differences of the earth current can be measured only on the northern half, we cannot form any definite conclusion, but in general we can make it clear. Data are in the table 5 and the relation graph is in Fig. 5.

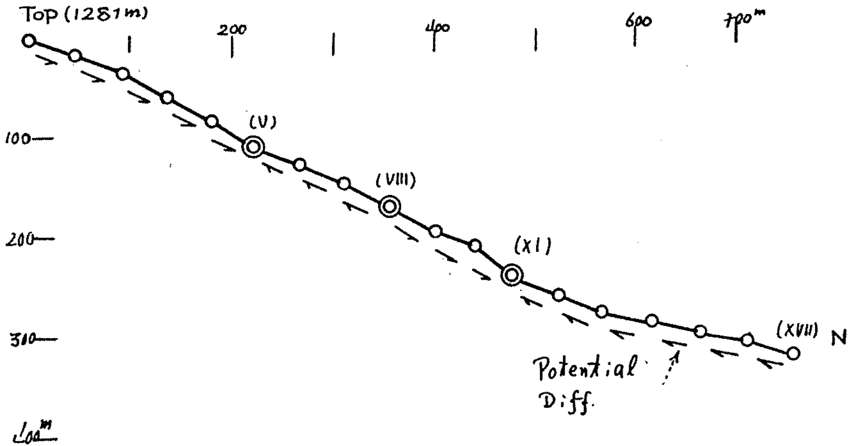


Fig. 5. Ôjo-dake Volcano.

§ 8. *The Ground of the Aso-Volcanic-Laboratory.* This ground is a layer of loam about 20 meters thick on the top of a mound-like hill which was made at the time of the first lava flow of the Eboshi-

Table 6. Data at the ground of the Aso-Volcanic-Laboratory.
(1936 May 20th.)

Points	(Top-1)	(1-2)	(2-3)	(3-4)	
H. D.	$\overset{\rightarrow}{6.42^{m}}$	$\overset{\rightarrow}{18.32}$	$\overset{\rightarrow}{18.33}$		......North
P. D.	$\overset{\rightarrow}{52.5^{mv}}$	$\overset{\rightarrow}{1.1}$			
H. D.	$\overset{\rightarrow}{0.33^{m}}$	$\overset{\rightarrow}{8.80}$	$\overset{\rightarrow}{9.31}$	$\overset{\rightarrow}{11.49}$	......South
P. D.	$\overset{\rightarrow}{100.8^{mv}}$	$\overset{\rightarrow}{1.1}$	$\overset{\leftarrow}{25.8}$	$\overset{\leftarrow}{28.8}$	
H. D.	$\overset{\rightarrow}{0.05^{m}}$	$\overset{\rightarrow}{6.19}$	$\overset{\rightarrow}{3.21}$	$\overset{\rightarrow}{11.07}$	......East
P. D.	$\overset{\rightarrow}{14.3^{mv}}$	$\overset{\rightarrow}{4.30}$	$\overset{\leftarrow}{1.5}$		
H. D.	$\overset{\rightarrow}{8.00^{m}}$	$\overset{\rightarrow}{15.94}$	$\overset{\rightarrow}{14.72}$	$\overset{\rightarrow}{10.48}$	......West
P. D.	$\overset{\rightarrow}{30.4^{mv}}$	0.0	$\overset{\leftarrow}{25.0}$		
Mean Values H. D.	$\overset{\rightarrow}{3.9^{m}}$	$\overset{\rightarrow}{12.31}$	$\overset{\rightarrow}{11.49}$	$\overset{\rightarrow}{11.01}$	
P. D.	$\overset{\rightarrow}{49.5^{mv}}$	$\overset{\rightarrow}{11.3}$	$\overset{\leftarrow}{17.8}$		

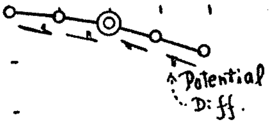


Fig. 6. Profile of Kenkyu-Sho-Yama.

dake. On the top of this hill (567.7 meters high), is the main building of the volcanic laboratory, a steel concrete structure about 40 m × 40 m. The ground is covered with grass only. The distributions of the earth current are very complicated as shown in table 6 and Fig. 6.

§ 9. *The Adjustment of the Observations.*

1). In general, the meeting point of the rising current and the falling current is at the west and north sides of the mountain top, and in the mean curve it disappears. This may show that the general current of the neighbouring earth current lies in this direction. Consequently, we can infer the direction of the earth current in that vicinity from the place of this changing point.

We arranged the observation points in symmetry on the other side of the mountain top, because we wanted to find only the distributions of potential. The general current of the field was eliminated.

2). As there is generally considerable thick loam on the mountain top, if there were no obstacles such as forests or buildings, we should have had sufficient results indicating the potential distributions in the direction which corresponds to the direction of the general earth current, at the top of any mountain of the cinder, toloide, and conide.

3). On the toloide, the conide and the lava flow, the potential caused by height differences is influenced and so the observed potential gradient of the earth current is very complicated.

4). The temperatures of the earth's surface at various observation points are not very different.

Table 7. Temperatures at the observation points.

Kome-tsuka=	Top	22.2°C (Surface)
	North foot	23.0°
	South	23.0°
	East	22.3°
	West	22.6°
Ôgi-yama=	Top	18.0°C
	South	18.0°
	North	18.0°
Yomine=	Top	18.0°C
	East foot	17.5
	West	18.0
	South	18.0
Ôjo-dake=	Top	17.5°C
	North	17.0

Volcanic Laboratory=	Top	17.5°C
	East foot	17.3
	West „	18.0
	North „	17.8
	South „	18.0

5). In spite of this, if we examine the height differences and the potential gradient of the earth current on a cinder cone, it may show comparatively smooth relation curves.

Inferring from the results above, I think that the cinder cone has a comparatively uniform structure, and the ascending electric current toward the mountain top is caused by the height differences, namely, the differences of the soil pressures or the differences of some other amount which changes parallel to the differences of soil pressure.

IV. The Relation between the Height Differences and the Potential Differences of the Earth Current

In connection with the nature of the potential difference observed above, the writer put the freshly dug soil (from about 10 cm. underground) into a bamboo tube of 11 cm. in inner diameter and 130 cm. in length, and buried the two poles and made the distance of the pole pieces to be 100 cm. The pole piece is an amalgamated zinc rod 1 cm. in diameter and 2 cm. in length as shown in Fig. 7. And then we

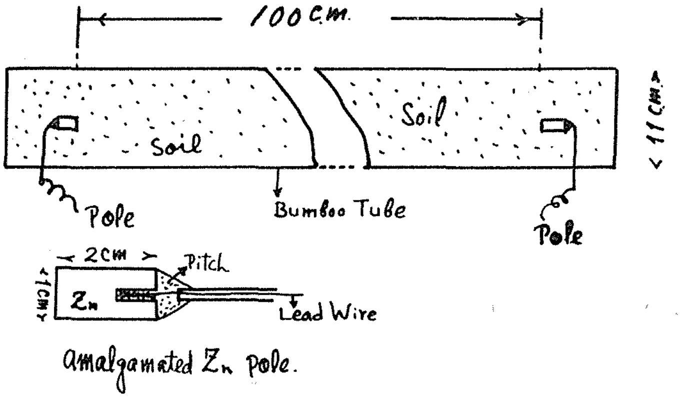


Fig. 7

stuffed the rubber cord with the zinc piece into the hole of the rod, and insulated the cord thoroughly with pitch. Both ends of the tube are insulated with rubber boards and once more fixed with wooden pieces. At the time of experiment, we increased or decreased the voltage differences between the poles, fixing one end and making the bamboo tube diagonal by moving the other end. After the preparations were made, we placed the bamboo tube level, and left it about 48 hours, keeping the temperature uniform.

For the measurement of potential differences we used the potentiometer of Leed and Northrup Co. and were able to read to 10^{-3} m. v. by the balance method.

Table 8. Potential Differences of a Soil Column under various Heights. (moderate moisture)

Time	Height Diff.	Voltage gained 1936 Sept. 28th.			
$10^{h}25^{m}$	20^{cm}	$+0.000233^{volt}$	$12^{h}40^{m}$	20^{cm}	$+0.000149^{volt}$
35	40	396	50	40	375
45	60	573	13 0	60	523
55	80	662	10	80	684
11 05	100	839	20	100	882
$11^{h}40^{m}$	20^{cm}	$+0.000226^{volt}$	Mean Values		
50	40	329		20^{cm}	$+0.000208^{volt}$
12 0	60	524		40	+ 368
10	80	702		60	+ 540
12 20	100	870		80	+ 682
				100	+ 864

Table 9. Potential Difference of a Soil Column under various Heights. (excessive moisture)

Time	Height Diff.	Voltage gained 1936 Sept. 25th.			
$11^{h}10^{m}$	20^{cm}	-0.000165^{volt}	$15^{h}20^{m}$	20^{cm}	-0.000158^{volt}
12 10	40	− 269	25	40	− 293
13 10	60	− 365	30	60	− 436
14 10	80	− 646	35	80	− 502
15 10	100	− 833	40	100	− 634
Mean Value	20^{cm}	-0.000162^{volt}			
	40	− 281	*Notice*		
	60	− 401	+Lower pole......positive		
	80	− 574	−Lower pole......negative		
	100	− 734			

Readings :—

1). First of all, we read the potential differences in the horizontal position.

2). Then one end was raised so that the height differences between the two poles became the desired value and another reading taken.

3). Again the tube was brought back to the level position, and a reading taken.

We finished this process within three minutes, and left it ten minutes as it was, and then measured at the next position. This result is shown in tables 8 and 9, Figs. 8 and 9.

This result agrees with the reports made by S. J. Mauchly* that the lower pole becomes positive potential when the soil is moistened moderately, and it becomes negative when the soil is excessively moist. And I found out that the height difference and the potential differences were in linear relation as shown in the figure.

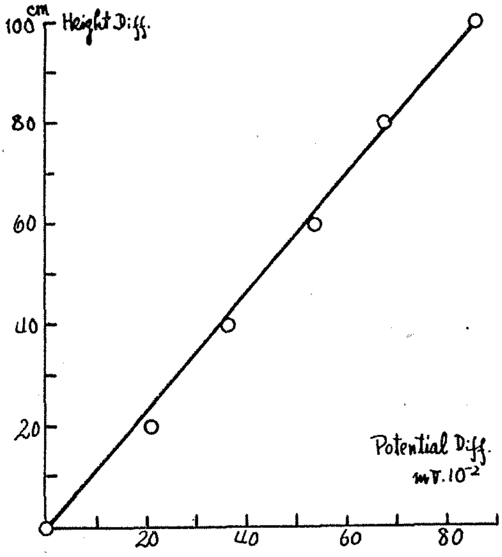


Fig. 8. Potential Differences of a Soil Column under various Pressures. (moderate moisture)

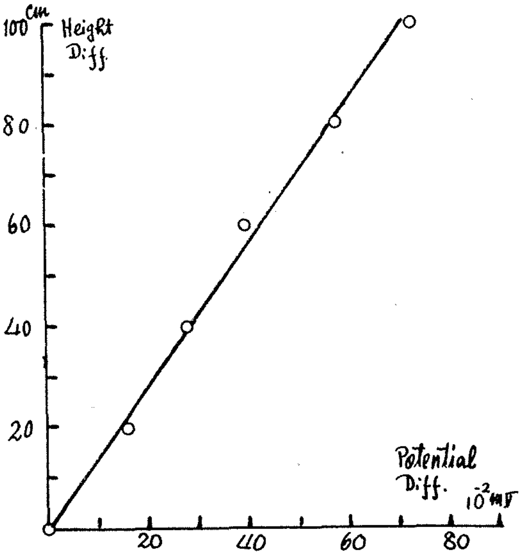


Fig. 9. Potential Differences of a Soil Column under various Pressures. (saturated moisture)

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* S. J. Mauchly :— A study of pressure and temperature effects in earth current measurements. Terr. Magn. and Atm. Electr. **23**, 1918, pp. 73-91.

Moreover, I noticed that the potential differences caused by the pressure differences were due to the phenomenon of the streaming potential. As in Mauchly's observation, the phenomenon that the upper pole becomes positive when the moisture is in excess, that is, the phenomenon making the ascending current disappear when the cataphoresis becomes vigorous, is the same with the phenomenon in the electrolyzable solution. On the contrary, the lower pole becomes positive in moderate moisture, the ascending current becomes stronger, and the cataphoresis weaker.

From these experiments, we may infer that it is the phenomenon of the streaming potential to produce the potential differences by the height differences of the soil column. Again briefly, when there is an excessive moisture, the colloidal particles are pressed down, and the so-called cataphoresis is produced; and in less moisture, the water is pressed down, and the so-called streaming potential is produced. And the potential differences generated in that case, using the result of Helmholtz, are as follows:—

$$E = \frac{P.D.\zeta}{4\pi.\eta.\lambda}$$ where

E: Potential gained.
P: Pressure.
D: Dielectric constant.
ζ : Potential of the double layer.
η : Coefficient of viscosity of the water.
λ : Specific conductivity of the soil.

In fact, the phenomenon of excessive moisture in the soil of the volcanic districts seldom happens and so the lower pole is usually positive on the surface of the earth.

Now the distribution of the "boden druck" under a "grundungs körper" is in general:

$$P = P_0 \cdot \left(1 - \frac{x^2}{a^2} - \frac{y^2}{b^2}\right)^m$$ where

$m > 1$
$P(x,y)$: boden druck at (xy),
P_0 : boden druck at the center,
a, b : constants.

As it is used in general,

$$P = P_0 \cdot \left(1 - \frac{x^2}{a^2}\right)$$ where $m = 1$, and x, y are in symmetry,

then the boden druck $= \Pi \cdot \int_0^{P_0} x^2 dP$.

Therefore $P_0 = \frac{2}{\Pi \cdot a^2}$(total boden druck).

The volcanic cone is not a uniform " grundungs körper " as in the above case, but if the mean pressures are distributed at each horizontal surface, the pressure P_0 at the center becomes as follows :—

Let the equation of the cone be $y=a\cdot c^{c_1x+c_2x^2+\cdots\cdots}$, $c>0$ and $y\doteqdot a\cdot c^{cx}$

then
$$P_0=\frac{2\cdot\rho\cdot g}{x^2}\int_a^y x^2\cdot dy$$
$$=2\cdot\rho\cdot g\cdot\left[y-2\cdot y\cdot\log^{-1}\frac{y}{a}+2(y-a)\log^{-2}\frac{y}{a}\right]$$

where ρ=density, g=980 cm/sec./sec.

This is concave toward the y axis when y is nearly equal to a, and becomes more concave toward the P axis when y is fairly large. If the potential gradient which was measured at the side of the cinder cone is caused by the difference of the maximum pressure P_0 on that level surface, it will be represented by the following equation :

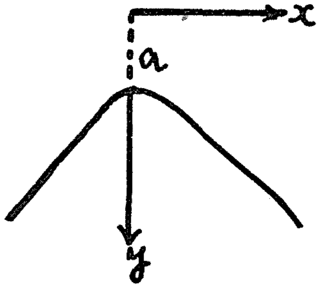

Fig. 10

$$\text{Potential difference}=\text{function }(P_0)$$
$$=a\cdot\left(y-\frac{2y}{\log y-\log a}+\frac{2(y-a)}{(\log y-\log a)^2}\right).$$

If the ascending current of the earth current which appears in a cinder cone which is comparatively not very high, may be mainly due as above to P_0, the potential difference must be a function of P_0 and, therefore, be a function of the altitude difference. Moreover if the potential differences caused by the height differences depend on the streaming potential, the specific conductivity, the dielectric constant and the viscidity of the water of each volcano play very important parts as shown in the equation. We found that the theoretical equation coincided with the result of the field observation on these points. That is to say that the ascending current which appears in a cinder cone comparatively not very high, may be mainly due to the streaming potential which is produced by the difference of the soil pressure in the altitude difference. If we use the result in reversal, it is possible to find out a cone to be either a cinder one or not.

In conclusion the author wishes to express his sincere thanks to Prof. T. Nomitsu for his kind advice and encouragement during the study.