An Investigation of Earth Currents on the Volcano Aso

Part III. The Influence of the Temperature of the Earth's Surface upon the Vertical Component of the Earth-current[1]

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Abstract

When the diurnal variation of the vertical component of the earthcurrent is compared with that of its horizontal component, there remain residuals independent of the latter. These residuals have fairly close relation to the daily variation of the earth-surface temperature, a presumable cause among others of the residuals.

The following facts have been elucidated by laboratory experiments.

1). The change of the earth-surface temperature brings about the change of the vertical component of the earth-current, the rise of the temperature causing it to rise "up." (The Writer uses the word "up" to indicate that the potential of the upper electrode becomes higher than the lower.)

2). Precipitation on the earth-surface brings about a similar effect, and causes it to rise "up."

3). The mechanism of such phenomena has been studied, and it is shown that they are most reasonably explained as the result of electro-osmosis in the upper layer of the earth.

I. Introduction

Bachmetjew[2] and S. H. Christie[3], believing that the thermo-electric current was generated by the action of the sun's heat on *different kinds* of soil, tried to examine the daily variation of terrestrial magnetism. Graves[4] noticed the change of potential difference of the earth-current occasioned by the sun's passage over the cable meridian and observed the difference in its mode according to whether it took place

1. Tikyu-Buturi (Geophysics), **2** (1938), 152.

2. Bachmetjew, P. Der gegenwärtige Stand der Frage über elektrische Erdströme. Mém. Acad. Soci., St. Pétersbourg, V. XII, No. 3, 1901, pp. 1–58.

3. Christie, S. H. Theory of the diurnal variation of the needle. Phil. Tran., 1827, p. 308.

4. Graves, J. Earth-currents with the Atlantic cable. Jour. Soc. Tel. Eng., II, 1873, pp. 102–123.

in the daytime or at night. Dickson[1] and Walker[2] observed that the potential difference of the upward earth-current flowing up toward the top of a mountain varied according to weather conditions at its summit.

The first subject noticed in the study of the vertical component of the earth-current was the effect of the difference in temperature between electrodes, and the matter has been examined with considerable throughness by S. T. Mauchly[3]. Then, S. E. Forbush[4] at Huancayo, South America compared the variation of the horizontal component of the earth's magnetism with that of the vertical component of the earth-current and obtained the residuals with a phase similar to the variation of atmospheric temperature. He regarded the direct influence of the atmospheric temperature upon the temperature of the electrodes as the possible cause of those residuals. But as the electrodes in his instrument had been buried in the earth at a depth of about 1.5 metres it may be questioned whether of the daily variation of atmospheric temperature exerted direct effect upon the temperature of the electrodes.

II. The daily variation of the horizontal components and the vertical component of the earth-current

The writer undertook the observation on the variation of the vertical component of the earth-current with the usual technique. The upper electrode had been buried two meters deep under the earth surface, the lower one also two meters deep under the bottom of a well, the distance between them being twenty meters. To begin with, a comparison was made of the general features of the variations of the vertical component and the horizontal components of the earth-current. The data on their mean daily variation for twenty days during February, 1939, is shown in Table 1 and Fig. 1, and its vector diagrams in Fig. 3 (A), and the data for eight days during May, 1939, in Table 2 and Fig. 2, and its vector diagrams in Fig. 3 (B). Also the data for seventeen days during June and August, 1931, at Huancayo in South America is shown in Table 3 and Fig. 4.

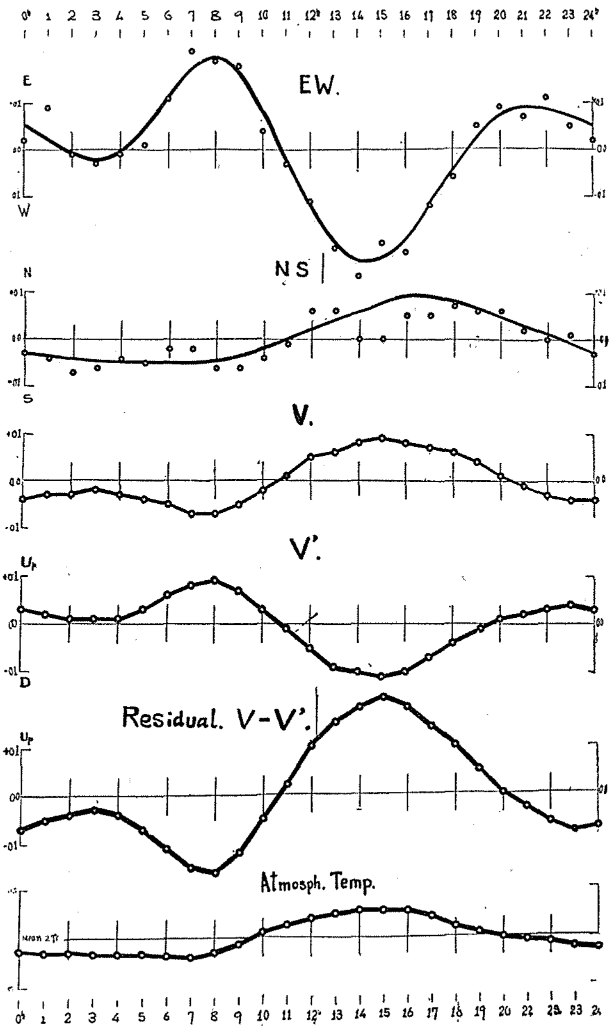
1. Dickson, Walker, E. O. Earth currents in india. Journ. Soc. Tel. Eng., Vol. XII, 1883, pp. 38-40: 163-164; V. XVII, 1888, pp. 239-248; V. XXII, 1893, pp. 214-225.

2. Atmospheric Electricity and Earth-currents. The Electrician (London), XLIX, 1902, pp. 833-834.

3. Mauchly, S. T. A study of pressure and temperature effects in the earth current measurements. Terr. Magn. Vol. 23, 1918, pp. 73-91.

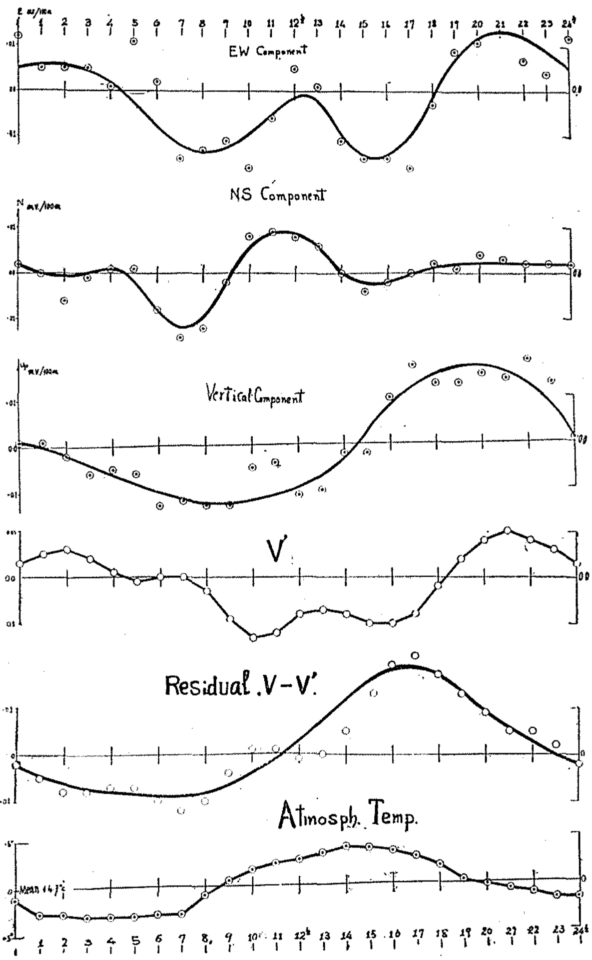
4. Forbush, S. E. Apparent Vertical Changes in Earth-current.........Terr. Magn. Vol. 38, No. 1, 1933.

Fig. 1. data of Feb. 1939, at Asô.



The actual record of the variation of the earth-current is as shown in Fig. 5 A. It is the record concerning the E-W component and the vertical component automatically taken on the same recording paper. The general features of the surroundings of the Aso Volcanic Laboratory may be judged from this record. Here the change of the vertical component upward and downward is accompanied by that of the horizontal components toward E. & S. and W. & N. respectively (at the period of the observation). Forbush reports the inverse case at Huan-

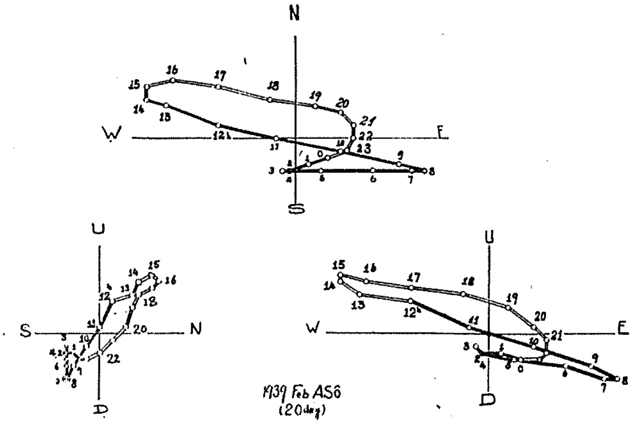
Fig. 2. data of May 1939 Asô.



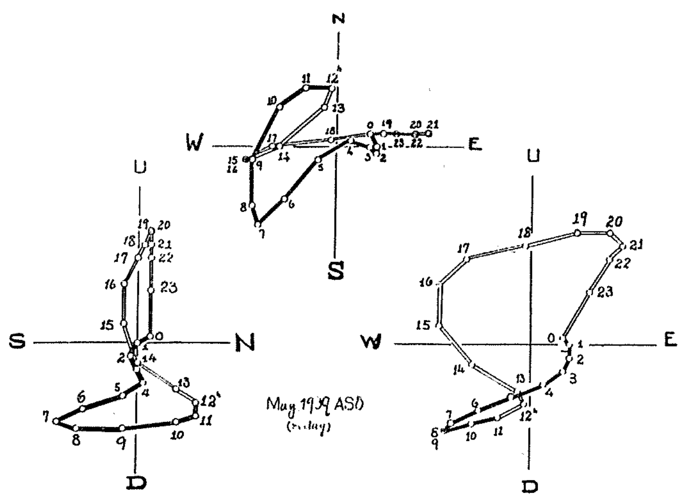
cayo and it is a noteworthy fact that at the Aso Laboratory also the case begins to reverse at the beginning of June (Fig. 5 B).

Whatever may be the cause of such changes, if we assume that the changes of the E-W, and N-S, and the vertical components are in a linear relationship to each other, then the same relationship is to be expected also between the value in the column 'EW-NS' and the vertical component V. Hence, the ratios of their absolute numbers have been calculated, and an average value of 2.9 was obtained. This means, the variation of the vertical component of the earth-current which is in linear relation with that of the horizontal components of

Fig. 3. (A)



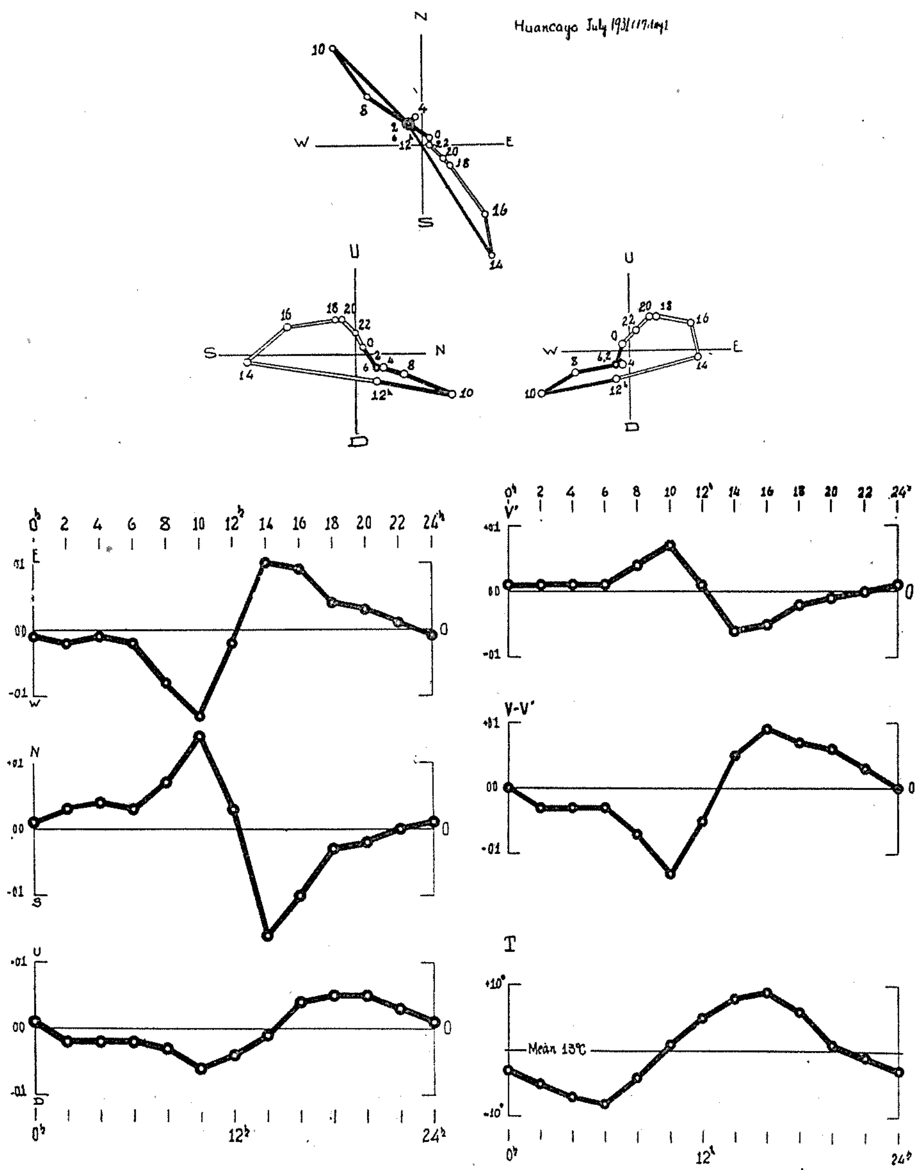
(B)



it must be equal to the latter multiplied by 1/2.9. If we denote this product by V′, then the value V-V′ expresses the residuals of the variation of the vertical component independent of the horizontal components.

As the cause of such residuals, many factors may be named, but first of all the effect of the earth-surface temperature will be discussed in this report.

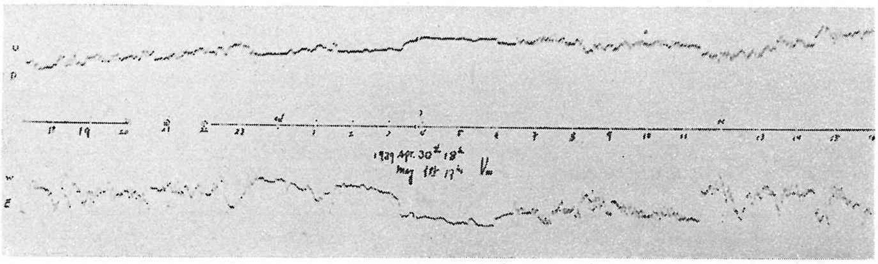
Fig. 4. data at Huancayo.



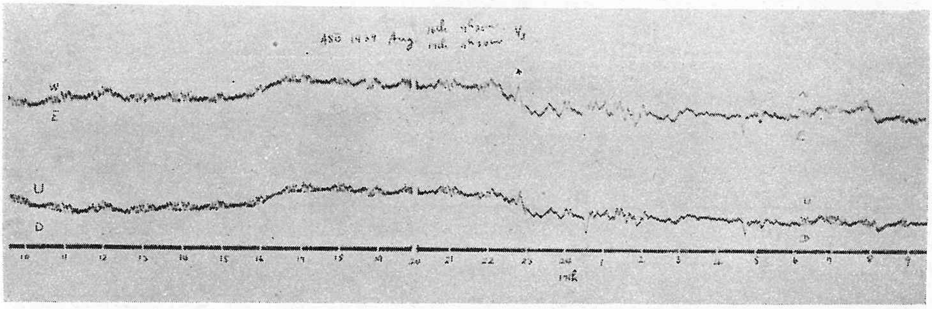
III. Experimental results with a soil column

A wooden box measuring one meter square and 2.5 meters in height was constructed, its inner surface being painted with asphalt in

Fig. 5. (A)



(B)



order to insure insulation. The box was filled with soil newly dug and as compact as possible. The upper electrode was buried 60 cm. below the surface and the lower one 1 meter beneath it. Before beginning measurement, it was left standing for at least a month in a room with little fluctuation in temperature.

(A). Effects of illumination.

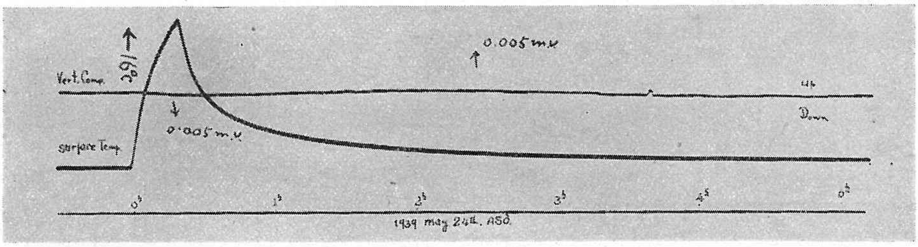
In the first place, the effects of long-distance illumination with a vita light lamp or other lamps upon the vertical potential difference and upon the soil surface temperature were recorded simultaneously. The result is as shown in Fig. 6, and the major interesting points are as follows.

(1) When the earth surface is illuminated intensely for a short time, the vertical component of the earth-current falls 'Down' at first, then it rises 'Up' and afterwards gradually returns to the original (Fig. 6A).

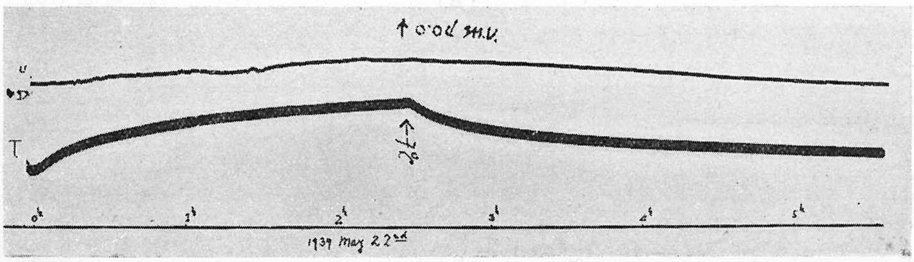
(2) With mild illumination for a long time, the vertical component rises 'up' from the outset, and then recovers in a manner almost similar to the earth-surface temperature (Fig. 6 B).

(3) These effects of illumination diminish considerably when the upper electrode is buried at a depth of 120 cm. below the earth-surface. (Fig. 6 C).

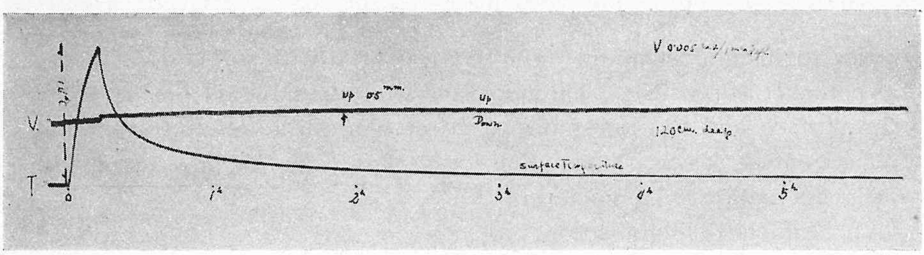
Fig. 6. (A)



(B)



(C)



(B) Effects of watering.

Study was also made of the effect of watering the earth surface evenly with a watering-pot, the temperature of water being adjusted to correspond with that of the earth-surface.

(1) With intense watering for a short time, there occurs rapid falling 'down' and gradual rising 'up' and lastly more gradual restoration. (Fig. 7).

(2) In the case of gentle watering, the rapid falling phase can not be observed.

The concrete figures run as follows: In the case of intense illumination (Fig. 6 A), the maximum soil surface temperature reached 16°C by some 20 minute illumination, while the potential change measured at first 0.005 mv Down, and then 0.005 mv Up. In the case

Fig. 7.

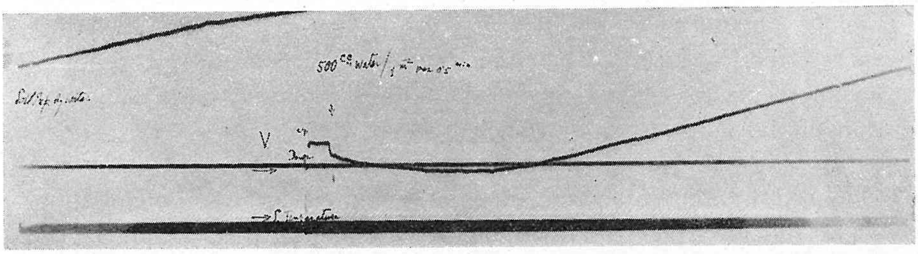
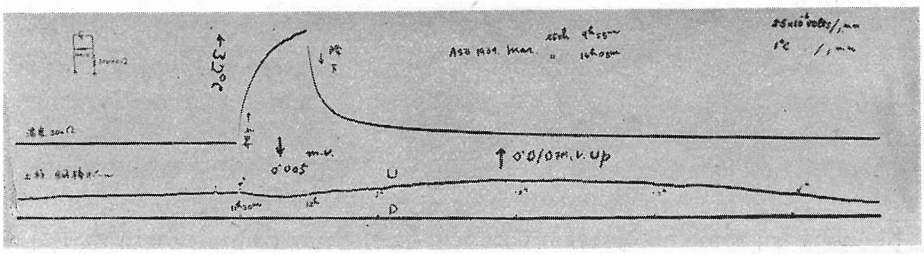


Fig. 8.



of mild illumination (Fig. 6 B), the maximum soil surface temperature reached 7°C by a 2.5 hour illumination, while the potential variation reached 0.04 mv Up. Fig. 8 records the same experimental result as Fig. 6 A, but the sensibility of the apparatus in the former case was raised to indicate the effect clearly.

Figures in the watering experiment: The earth-surface of 1 square meter was watered with 500 gr of water per minute. This is equal to the rate of 30 mm precipitation per hour, or 720 mm per day. The first effect was the rapid falling 'Down' of 0.01 mv and then a gentle fall measuring 0.02 mv 'Down' after 1 hour. Afterward it turned toward Up, the maximum reading reaching 0.15 mv Up after 10 hours, and at last it recovered after 30 hours from the beginning of the experiment. (Fig. 7).

Although the experimental conditions may be considerably divergent from the natural ones, if we are allowed for present purposes to assume the soil pile to represent a part of the earth, the following conclusions may be drawn. When there is a gentle daily variation of about 16°C in the earth surface temperature, the vertical component of the earth-current may possibly show a variation of about 0.12 mv or more with the same phase as the variation in the earth surface temperature. Concerning the effect of precipitation, a general idea may be gained from the experimental results above described:—The vertical component of the earth-current will rise 'up', and its magnitude may possibly amount to a considerable figure. But the fact that the effect was reduced to one half when the electrode was buried at a depth of 120 cm seems to suggest the considerable diminution in the daily variation of the earth-current in such a case.

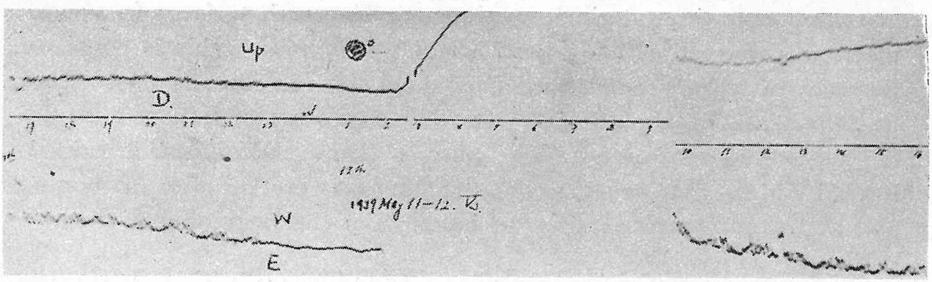
In short, the so-called vertical component of the earth-current is influenced by the soil-surface temperature and by the precipitation. But if the electrode is buried about two meters deep or more, the effects of both seem to diminish greatly.

IV. In the previous sections, it has been shown

Experimentally that both the sun's radiations and precipitation may be factors in the variation of the earth-current, and that the following qualitative conclusion is admissible, viz.: that gentle rays of the sun or mild precipitation may become a source of positive local earth-current. Before proceeding to the discussion of the nature of these phenomena, some observation data will be cited in connection with the above facts.

(a) The change in the vertical component of the earth-current produced by the rain in the morning, May 20th, 1939, showed obvious rising 'up' while the record of the E-W component scaled out toward E (Fig. 9).

Fig. 9.



(b) The report of the observation on the potential difference between the summit and the foot of a mountain at the Ben Nevis Observatory tells us that when the summit was habitually covered with fog, the temporary clearing of the summit generated the earth current flowing upwards along the cable and this ceased when the summit was again veiled in fog; rain and snow generated the earth-current flowing downwards.[1]

1. Wolker, E. O. ioc. cit.

(c) According to the observation of Palmieri at Mt. Vesuvius, the earth-current flowed up in fair weather while it flowed down on a rainy or snowy day.[1]

(d) The earth-current flows from open land toward a forest.[2]

Our own experimental results confirmed these findings and their explanation is clear.

Then what is the cause of such phenomena? The following is an epitome of the writer's opinion in explanation of the above facts. The rise in the temperature of the earth surface will presumably bring about expansion of the surface layer, and this in turn the phenomenon of so-called migration potential due to the upward migration of colloidal particles in the lower layer. The upper electrode in the vicinity will be influenced and its potential will rise. But the effect will be diminished when the electrodes are buried deeper. When the temperature of the surface rises rapidly, the sudden expansion of the surface layer of earth may effect pressure downward, causing the lowering of the potential of the upper electrode.[3] The effect of precipitation may be explained as follows. In the upper layer of earth, a streaming potential will be generated as the result of the permeation of water which will cause the potential or the upper electrode to rise. As the permeation of water proceeds to the deeper layer, the rate of rise 'Up' of the potential will increase, but at last the permeation proceeds to the layer still deeper than that of the upper electrode and the rise of the potential of the lower electrode may finally exceed that of the upper one. But in the actual case, since the permeation of water to such a deep layer must probably take place only after a long time, the final effect may escape ordinary observation. Thus precipitation will manifest itself only in the rise of the potential of the upper electrode. But when the precipitation is very intense, its weight may possibly become a major factor in causing the first lowering of the potential (Down). Of course, as the rain drop often has considerable free ions, the above reasoning may sometimes be inapplicable.

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1. Palmieri, D. Observations on earth-currents at the Vesuvius Observatory, etc. Atti. Acad. Napoli, 1894, VI, 2a No. 12, pp. 1-10; 1895, VII, 2a No. 6, pp. 1-7.

2. Burbank, J. E. Earth-currents and a proposed method for their investigation. Terr. Mag. Vol. 10, 1905. pp. 23-49.

3. Namba, M. An Investigation of Earth-current on the Volcano Aso. Part I. The Potential Difference of the Upward Earth-current flowing toward the top of a Volcano. 1938, This Mem. Vol. XXI, No. 6, p. 213.

In the writer's opinion, the experimental results and also the various observation data mentioned above can thus be satisfactorily interpreted, and the previous statement that "Both the sun's radiation and precipitation may be factors in the variation of the earth-current" is confirmed. And also the residuals obtained in the daily variation of the vertical component of the earth-current noticed in the first part of this paper are reasonably to be expected.

Lastly, one more word: The real figures for such effects of the earth surface temperature cannot be found by mere experiment and it is necessary to make calculations from many actual observation data before the study can be considered complete.

This work was carried out under the encouragement of Prof. Dr. T. Nomitu and the support of the Japanese Society for the Advancement of Sciences, and the writer wishes to take this opportunity to express his gratitude.

Tabl I. Mean Daily Variations of the Earth-current at Asô, Feb. 1939.

	$EW \frac{\text{mv}}{100^{\text{m}}}$	$NS \frac{\text{mv}}{100^{\text{m}}}$	$V \frac{\text{mv}}{100^{\text{m}}}$	$\left\|\frac{E-N}{V}\right\|$	$\frac{E-N}{2.9} \equiv V'$	$V-V'$	Atmosp. Temp.
0 h	0.05	−0.03	−0.04	2.0	0.03	−0.07	−1.3°C
1 h	0.02	−0.04	−0.03	2.0	0.02	−0.05	−1.5
2 h	−0.01	−0.05	−0.03	1.3	0.01	−0.04	−1.5
3 h	−0.02	−0.05	−0.02	1.5	0.01	−0.03	−1.6
4 h	−0.01	−0.05	−0.03	1.3	0.01	−0.04	−1.7
5 h	0.04	−0.05	−0.04	2.3	0.03	−0.07	−1.7
6 h	0.12	−0.05	−0.05	3.4	0.06	−0.11	−1.9
7 h	0.18	−0.05	−0.07	3.3	0.08	−0.15	−2.0
8 h	0.20	−0.05	−0.07	3.6	0.09	−0.16	−1.5
9 h	0.16	−0.04	−0.05	4.0	0.07	−0.12	−0.7
10 h	0.07	−0.02	−0.02	4.5	0.03	−0.05	−0.5
11 h	−0.03	0.00	0.01	3.0	−0.01	0.02	1.2
12 h	−0.12	0.02	0.05	2.8	−0.05	0.10	1.9
13 h	−0.20	0.05	0.06	4.2	−0.09	0.15	2.4
14 h	−0.23	0.06	0.08	3.6	−0.10	0.18	2.7
15 h	−0.23	0.08	0.09	3.4	−0.11	0.20	2.7
16 h	−0.19	0.09	0.08	3.5	−0.10	0.18	2.7
17 h	−0.12	0.08	0.07	2.6	−0.07	0.14	2.1
18 h	−0.04	0.06	0.06	1.7	−0.04	0.10	1.0
19 h	0.03	0.05	0.04	0.5	−0.01	0.05	0.4
20 h	0.07	0.04	0.01	3.0	0.01	0.00	−0.1
21 h	0.09	0.02	−0.01	7.0	0.02	−0.03	−0.4
22 h	0.09	0.00	−0.03	3.0	0.03	−0.06	−0.7
23 h	0.08	−0.02	−0.04	2.5	0.04	−0.08	−1.1
				Mean 2.9		(Residuals)	Mean

Tabl 2. Mean Daily Variations of the Earth-current at Asō, May. 1939.

	$EW\frac{\text{mv}}{100^{\text{m}}}$	$NS\frac{\text{mv}}{100^{\text{m}}}$	$V\frac{\text{mv}}{100^{\text{m}}}$	$\frac{\lvert EW-NS\rvert}{V}$	$\frac{EW-NS}{1.2}\equiv V'$	$V-V'$	At. Temp.
0 h	0.05	0 02	0 01	3 0	0.03	−0.02	−1.1
1 h	0.06	0.00	0.00		0.05	−0.05	−2.7
2 h	0.06	−0.01	−0.02	3.5	0.06	−0.08	−2.8
3 h	0.05	0.00	−0.04	1.3	0.04	−0.08	−3.1
4 h	0.02	0.01	−0.06	0.2	0.01	−0.07	−3.1
5 h	−0.03	−0.02	−0.08	0.1	−0.01	−0.07	−3.1
6 h	−0.08	−0.08	−0.10	0	0.00	−0.10	−2.9
7 h	−0.12	−0.12	−0.12	0	0.00	−0.12	−2.9
8 h	−0.13	−0.09	−0.13	0.3	−0.03	−0.10	−0.9
9 h	−0.13	−0 02	−0.13	0.9	−0.09	−0.04	0.6
10 h	−0.09	0.06	−0.12	1.3	−0.13	0.01	1.7
11 h	−0.05	0.09	−0.11	1.3	−0.12	0.01	2.8
12 h	−0.01	0.09	−0.09	1.1	−0.08	−0.01	2.7
13 h	−0.02	00.6	−0.07	1.1	−0.07	0.00	3.4
14 h	−0.09	0.00	−0.03	3 0	−0.08	0.05	4.0
15 h	−0.14	−0.02	0.03	4.0	−0.10	0.13	3.8
16 h	−0.14	−0.02	0.09	1.3	−0.10	0.19	3 4
17 h	−0.10	0.00	0.13	1.0	−0.08	0.21	2.8
18 h	−0.01	0.01	0.15	0.1	−0.02	0.17	1.8
19 h	0.07	0.02	0.17	0.3	0.04	0.13	0.3
20 h	0.12	0.02	0.17	0.6	0.08	0 09	−0.2
21 h	0.14	0.02	0.15	0.8	0.10	0.05	−0.7
22 h	0.12	0.02	0.13	0.8	0 08	0.05	−1.1
23 h	0.09	0.02	0.08	0.9	0.06	0.02	−1.7
				Mean 1.2		(Residuals)	(Mean)

Tabl 3. Mean Daily Variations of the Earth-current at Huancayo, July-Aug., 1931.

	$EW\frac{\text{mv}}{100^{\text{m}}}$	$NS\frac{\text{mv}}{100^{\text{m}}}$	$V\frac{\text{mv}}{100^{\text{m}}}$	$EW-NS$	$\frac{\lvert EW-NS\rvert}{V}$	$\frac{EW-NS}{4.3}\equiv V'$	$V-V'$	Atmoph. Temp.
0 h	−0.01	0.01	0.01	−0.02	2.0	0.01	0.0	−3°C
1 h								
2 h	−0.015	0.03	−0.015	−0.05	2.5	0.01	−0.03	−5
3 h								
4 h	−0.010	0.035	−00.15	−0.05	2.5	0.01	−0 03	−7
5 h								
6 h	−0.018	0.030	−0.020	−0.05	2.5	0.01	−0.03	−8
7 h								
8 h	−0.08	0.070	−0.030	−0.15	5 0	0.04	−0.07	−4
9 h								
10 h	−0.132	0.140	−0 060	−0.27	4.5	0.07	−0.13	1
11 h								
12 h	−0.020	0.030	−0.040	−0.05	1.3	0 01	−0.05	5
13 h								
14 h	0.100	−0.160	−0.010	0.26	26.0	−0.06	0.05	8
15 h								
16 h	0.090	−0.100	0.040	0.19	4.8	−0.05	0.09	9
17 h								
18 h	0.040	−0.030	0.050	0.07	1.4	−0.02	0.07	6
19 h								
20 h	0.030	−0.020	0.050	0.05	1.0	−0 01	0.06	1
21 h								
22 h	0.010	0.00	0.030	0.01	0.3	0.00	0.03	−1
23 h								
					(Mean 4.3)			(Mean)