13. *Diffraction of Electromagnetic Waves around the Crater of Volcano Mihara.*

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1. Introduction.

Geophysical investigations of various sorts were carried out in connexion with the recent eruption of Volcano Mihara, Ooshima (Oo-sima) Island. One of the investigations carried out was the magnetic dip survey executed by the writer throughout the island in July and September, 1950. At the second survey, the writer's party prepared a portable radio-receiver in order to catch the weather forecasting. As a loop antenna was used for the receiver, the direction of the polarization of the broadcasting radio-wave could be determined readily. Some studies concerning the diffraction of the radio-wave around the crater were made with this receiver for the purpose of inferring the electric properties of the high temperature lava filling in the crater.

According to the measurement of the electrical conductivity of igneous rocks at high temperature[1), 2)], it was already found out that the conductivity increases with the increase in temperature amounting to the order of $10^{-11}\sim10^{-10}$ *emu* at about 1,000° *C* though it is as low as 10^{-16} *emu* at the ordinary temperature. At the time of the eruption of Volcano Sakura-jima of 1946, T. Nagata[3)] and others actually proved that the electrical conductivity in the moving lava-flow is considerably high.

The present measurement was carried out during the days Sept. 24 and 25. Though the eruption stopped in the night of Sept. 23, the temperature of the lava was so high that the lava-flows which overflowed the central cone were still moving down the slope. Hence, the lava filling in the crater is thought to be electrically conducting and, consequently, radio waves from JOAK Broadcasting Station may be diffracted by the lava mass which has a dimension comparable with the wave length.

1) T. NAGATA, *Bull. Earthq. Res. Inst.*, **15** (1937), 663.

2) H. P. COSTER, *M. N. R. A. S. Geophys. Suppl.*, **5** (1949), 193.

3) T. NAGATA, S. SAKUMA and N. FUKUSHIMA, *Bull. Earthq. Res. Inst.*, **24** (1946), 161.

2. Measurement.

JOAK broadcasting wave of 590 *kc* sent from Kawaguchi about 100 *km* distant in the NNE direction were received. The loop antenna fixed to the receiver was mounted on a tripod. Rotating the horizontal circle, the direction of minimum signal was determined with a crystal receiver. As the receiver was a super-heterodyne one, the out-put signal voltage was sufficiently intense for the determination. According to the experiment, the direction was determined within an error of 1 *degree*. At the same time, the directions of several marks such as triangulation point were read on the horizontal circle with the aid of a simple finder attatched to the receiver. With these directions, the position of the measuring points and the azimuth of the polarization were determined. Thus the ultimate accuracy of the determination of the polarization-azimuth may amount to 2 or 3 *degrees*.

The measurement was made at 15 points in the caldera where tree or humid soil were not found. As the dry rocks are almost non-conducting, the anomalous distribution of the polarization of the radio wave, if it exists, may be attributed to the diffraction around the lava mass. The direction of maximum signal are shown in Fig. 1 together with the topography and the position of the measuring points. The direction from which the broadcasting waves are coming is also shown with an arrow. As seen in the figure, the direction of maximum intensity differed appreciably from place to place though their general direction agreed with the arrow, the largest deviation amounting to as

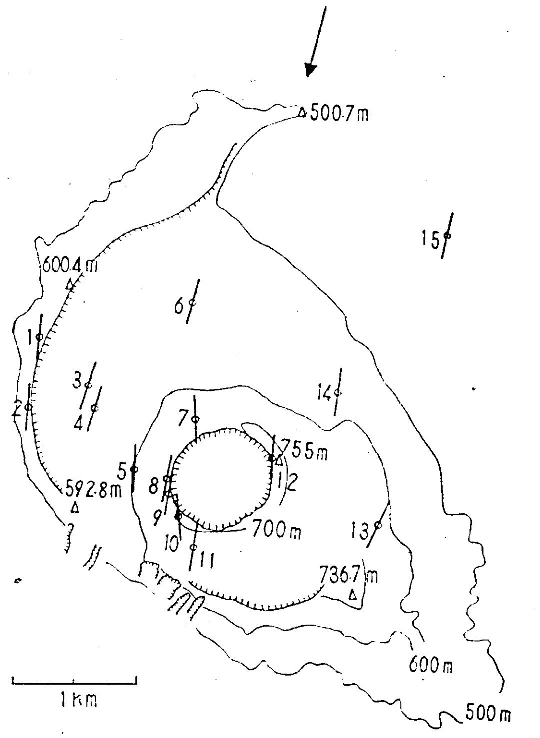

Fig. 1 The directions of maximum signal around the crater of Volcano Mihara. The arrow shows the direction from which JOAK broadcasting waves are coming.

much as 18 *degrees* as shown in Table I.

3. Interpretation of the results.

Although it is difficult to form a detailed estimate of the diffraction of the radio waves owing to the complicated shape of the lava mass, we may, to a rough degree of approximation, regard the lava mass as a conducting cylinder having a diameter of about 800 *m*. As the wave length of the incident wave amounts to 508 *m*, which is comparable with the dimension of the diffracting body, it is conceivable that the pattern of the diffracted waves will become much complicated.

According to the theory of the propagation of electric ground wave[4], the vector of the electric field slightly inclines to the direction of propagation. Neglecting the slight inclination just mentioned, we shall take here a plane wave as the incident wave such as expressed by

$$E_z = e^{i(k_1 x - \omega t)} \; (k_1 = \omega/c) \; , \qquad (1)$$

where ω and c denote respectively the angular frequency and the light-velocity. The horizontal components E_x and E_y are assumed to be zero. According to the theory[5] of diffraction around an infinite cylinder with perfect conductivity, the electric field outside the conductor is given by

$$E_z = e^{ik_1 x} - \sum_{-\infty}^{\infty} i^n J_n(k_1 a) \frac{H_n^{(1)}(k_1 r)}{H_n^{(1)}(k_1 a)} e^{in\phi} . \qquad (2)$$

In this expression, the time-factor is neglected. a denotes the radius of the cylinder, while r and ϕ are the cylindrical coordinate of which the origin is taken at the centre of the cylinder. On differentiating with respect to r and ϕ, the real part of the accompanying magnetic field-components are obtained as follows;

$$\begin{aligned} H_\phi = -\Big[& \cos k_1 x \cdot \cos\phi - \frac{J_0(k_1 a)}{|H_0^{(1)}(k_1 a)|} \{ J_0(k_1 a) Y_0'(k_1 r) - Y_0(k_1 a) J_0'(k_1 r) \} \\ & + 2\sum_{n=1}^{\infty} (-1)^n \frac{J_{2n-1}(k_1 a)}{|H_{2n-1}^{(1)}(k_1 a)|} \{ J_{2n-1}(k_1 a) J_{2n-1}'(k_1 r) + Y_{2n-1}(k_1 a) Y_{2n-1}'(k_1 r) \} \cos(2n-1)\phi \\ & - 2\sum_{n=1}^{\infty} (-1)^n \frac{J_{2n}(k_1 a)}{|H_{2n}^{(1)}(k_1 a)|} \{ J_{2n}(k_1 a) Y_{2n}'(k_1 r) - Y_{2n}(k_1 a) J_{2n}'(k_1 r) \} \cos 2n\phi \Big] \cos \omega t \end{aligned}$$

4) J. Zenneck, *Ann. d. Phys.*, **23** (1907), 846.

5) P. Frank, *Die Differential- und Integralgleichungen der Mechanik und Physik*, II, (1927), p. 494.

$$-\Big[\sin k_1x\cdot\cos\phi+\frac{J_0(k_1a)}{|H_0^{(1)}(k_1a)|}\{J_0(k_1a)J_0'(k_1r)+Y_0(k_1a)Y_0'(k_1r)\}$$

$$+2\sum_{n=1}^{\infty}(-1)^n\frac{J_{2n-1}(k_1a)}{|H^{(1)}_{2n-1}(k_1a)|}\{J_{2n-1}(k_1a)Y'_{2n-1}(k_1r)-Y_{2n-1}(k_1a)J'_{2n-1}(k_1r)\}\cos(2n-1)\phi$$

$$+2\sum_{n=1}^{\infty}(-1)^n\frac{J_{2n}(k_1a)}{|H^{(1)}_{2n}(k_1a)|}\{J_{2n}(k_1a)J'_{2n}(k_1r)+Y_{2n}(k_1a)Y'_{2n}(k_1r)\}\cos 2n\phi\Big]\sin\omega t\,,$$

$$H_r=\Big[\cos k_1x\cdot\sin\phi+\frac{2}{k_1r}\sum_{n=1}^{\infty}(-1)^n(2n-1)\frac{J_{2n-1}(k_1a)}{|H^{(1)}_{2n-1}(k_1a)|}\{J_{2n-1}(k_1a)J_{2n-1}(k_1r)$$

$$+Y_{2n-1}(k_1a)Y_{2n-1}(k_1r)\}\sin(2n-1)\phi$$

$$-\frac{2}{k_1r}\sum_{n=1}^{\infty}(-1)^n(2n)\frac{J_{2n}(k_1a)}{|H^{(1)}_{2n}(k_1a)|}\{J_{2n}(k_1a)Y_{2n}(k_1r)-Y_{2n}(k_1a)J_{2n}(k_1r)\}\sin 2n\phi\Big]\cos\omega t$$

$$+\Big[\sin k_1x\cdot\sin\phi+\frac{2}{k_1r}\sum_{n=1}^{\infty}(-1)^n(2n-1)\frac{J_{2n-1}(k_1a)}{|H^{(1)}_{2n-1}(k_1a)|}\{J_{2n-1}(k_1a)Y_{2n-1}(k_1r)$$

$$-Y_{2n-1}(k_1a)J_{2n-1}(k_1r)\}\sin(2n-1)\phi$$

$$+\frac{2}{k_1r}\sum_{n=1}^{\infty}(-1)^n(2n)\frac{J_{2n}(k_1a)}{|H^{(1)}_{2n}(k_1a)|}\{J_{2n}(k_1a)J_{2n}(k_1r)$$

$$+Y_{2n}(k_1a)Y_{2n}(k_1r)\}\sin 2n\phi\Big]\sin\omega t\,. \qquad \ldots\ldots(3)$$

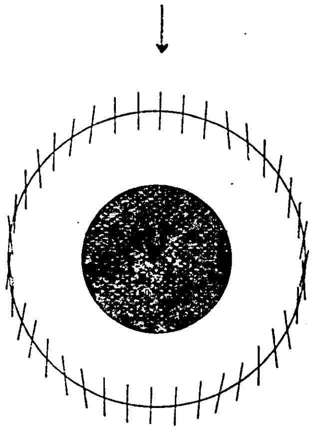

Fig. 2 The directions of maximum signal on a circle, the radius of which being two times larger than that of the diffracting cylinder.

With these expressions, the direction of the maximum intensity measured by the loop antenna is calculated for any point. For instance, the calculated directions on a circle whose radius is equal to $2a$ are illustrated in Fig. 2. As already expected, the complicated distribution of the direction is shown remarkably in the figure, the effect of the diffraction being so considerable that maximum deviation of the direction exceeds 11 *degrees.*

On the other hand, the said direction for the respective measuring points are calculated, their deviation from the incident direction are given in Table I together with the observed deviations. The calculated directions fairly agree with the observed ones except the points on the central cone, these points being situated within several *meters* from the margin of the high temperature lava mass. Thus the simple approximation for the diffracting body will be inadequate for these points.

Table I

The measured and calculated deviation of the direction of maximum intensity from the incident direction of the broadcasting radio wave. Westward deviation is taken to be plus.

Station	Distance from the centre of the crater	Measured deviation	Calculated deviation	Difference
No. 1	1840*m*	6°	6°	0°
No. 2	1640	9	6	3
No. 3	1280	–5	–3	–2
No. 4	1140	–3	–2	–1
No. 5	680	8	12	–4
No. 6	1460	–1	–1	0
No. 7*	500	12	1	(11)
No. 8*	420	3	–19	(22)
No. 9*	420	5	–22	(27)
No. 10*	420	18	–14	(32)
No. 11	580	2	0	2
No. 12*	480	11	–11	(22)
No. 13	1300	–13	–10	–3
No. 14	1180	5	3	2
No. 15	2760	–1	0	–1

(* These points are very near to the boundary of the lava, the distances being almost several *meters*.)

Taking into account the accuracy of measurement, it may be said that the general tendency of the anomalous deviation of the direction of maximum intensity is roughly explained as the diffraction of the electric waves around the conducting cylinder having the same area as that occupied by the lava mass.

4. Discussion.

In the previous section, the effect of the lava mass was assumed to be the same with that of a cylinder of infinite conductivity. On this point some discussions will be attempted here. When a plane wave is reflected by a semi-infinite conductor, the reflecting power is approximately given by

$$R = \frac{\sqrt{i\sigma}-\sqrt{\omega}}{\sqrt{i\sigma}+\sqrt{\omega}},$$

for relatively high conductor, where σ denotes the conductivity. The polarization of the electric vector is assumed to be parallel to the boundary. The reflecting power for various conductivity is calculated for the waves of 590 *kc* as shown in Fig. 3. As clearly shown in the figure, the conductor having higher conductivity than 10^{-12} *emu* may be considered to be equivalent to the perfect conductor in the calculation. Hence, the treatment in the former sections will be allowed, provided the conductivity of the lava at 590 *kc* does not differ materially from that for direct current as obtained by Nagata and Coster, the conductivity obtained by them being as high as 10^{-10} *emu* at the temperature of about 1,000° *C*.

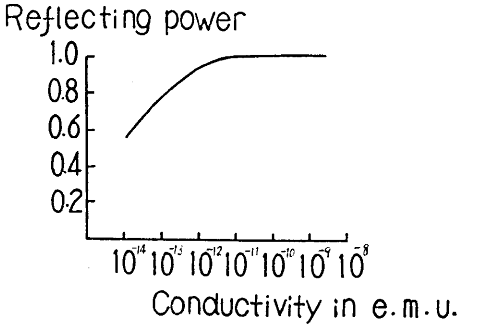

Fig. 3 The relation between the reflecting power for 590 *kc* wave and the electrical conductivity.

5. Conclusion.

As a result of the polarization measurement of the broadcasting radio waves in the vicinity of the crater of Volcano Mihara, some anomalous distribution of the polarization was found out. The distribution is roughly explained as the diffraction-effect around the high temperature lava mass filling in the crater. However, the detailed determination of the conductivity is impossible by the present simple measurement. Systematic measurements with electric waves having various frequencies will be needed for the more accurate determination of the electric properties of the lava.

In conclusion, the writer wishes to express his sincere thanks to Mr. S. Saito who constantly assisted the writer in the course of the measurement.

13. 三原山火口附近における放送電波の廻折

地震研究所 力 武 常 次

ループアンテナ使用の携帯用ラジオ受信機により，三原山外輪山内の十數箇所においてJOAK放送電波 (590 kc) の到來方向を測定して，最大 18° に達する偏倚を見出した。この異常は舊火口に充滿している高溫熔岩が高電導度を有するための廻折現象として理解される。