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82. *Electric Resistivity Measurement along and across a Ground Fissure in the Matsushiro Area.*

By Kaoru Kawada,

Earthquake Research Institute.

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Abstract

A number of ground fissures running through a village on the fan to the north of Mt. Minakamiyama took place in association with the Matsushiro Earthquake Swarm.

The author measured the apparent electric resistivity of the ground on lines perpendicular and parallel to one of the fissures at Takehara Village during a four week's period since the fissure appeared.

The effect of the fissure on earth resistivity could not be clearly observed probably because of complicated layering and resistivity anisotropy. Although the resistivity values fluctuated to a surprisingly large extent, say 20 per cent or so, no marked correlation between the fluctuations and earthquake occurrences were recognized.

1. Introduction

The activity of the Matsushiro Earthquake Swarm which started in August, 1965, became very active around April, 1966 although it had been moderate during a few months prior to April. A ground fissure was found at Takehara Village to the north of Mt. Minakamiyama immediately after an earthquake on April 8, 1966, the magnitude of which was 4. One of the inhabitants in the village was convinced that the fissure was produced at the time of the earthquake. Two earthquakes on April 11, their magnitudes estimated as being 4 and 5 respectively, accelerated the growth of the fissure. Indeed, the width of the fissure become as wide as 10 *cm* at maximum while the length exceeded 300 *m*. Two more fissures were later discovered near Takehara Village, one in Sezeki-Makiuchi Village and the other on Mt. Tennozan (see Fig. 1).

The present work is aimed at studying the depth of the fissures by measuring electric resistivity of the ground because it is important to know whether or not these fissures have something to do with possible land deformation in the deep. It would also be of extreme interest if a time-variation of the apparent electric resistivity is observed in association with occurrences of earthquakes. For such reasons the author conducted a series of resistivity measurements over the fissured area.

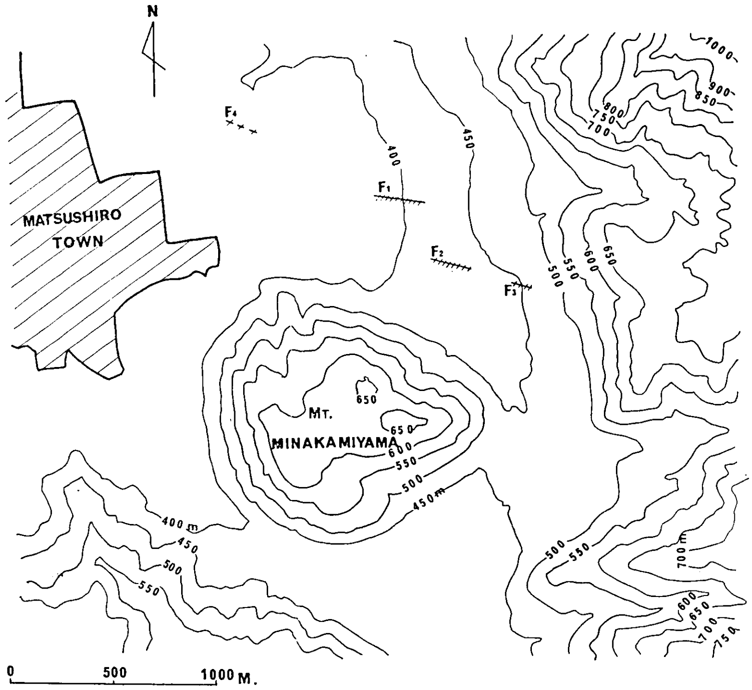

Fig. 1. Topographic map of area around Mt. Minakamiyama.
F_1: Takehara Fissure, F_2: Sezeki Fissure, F_3: Makiuchi Fissure,
F_4: Mt. Tennozan Fissure.

In Section 2 will be described the ground fissures observed together with the geology there. The method of resistivity measurement will be described in Section 3. A laboratory model experiment, which may be useful for inferring depth of fissures on the basis of resistivity measurements at a number of electrode distances, will be outlined in Section 4. Actual results of the field observation will be given in Section 5 which is followed by discussion and interpretation in Section 6.

2. Ground fissures and geology

The fans extending on the foot of Mt. Kimyozan cover the porphyrite-diorite basement formed in the Miocene age. The upper layer of the fans seems to be composed of sand and mud including pieces of the Kimyozan lavas which flew some time in the Pliocene age. Meanwhile the deeper layer is supposed to include fanglomerate eroded from the porphyrite-diorite zone. Takehara Village is situated on a contact line between two of these fans. There are several springs of ground water along the western edge of the village. The fissures growing since the middle of April run nearly from east to west. Although some researchers supposed that they were caused simply by a landslide of the upper layer of the fan, an enormous extension of the ground in the *NS* direction as observed by geodimeter work compels geophysicists[1] and geologists to suspect something extraordinary to have taken place even on the ground surface in the central area of the seismic activity. The occurrence of the Takehara fissure could be expected well beforehand in that sense. Two more fissures, moreover, appeared later following the Takehara fissure. Taking into consideration the fact that these fissures are parallel with one another, geologists believe that the fissures are caused by a structural displacement occurring in the porphyrite-diorite basement or even in the deeper Mesozoic granite supposed to lie at a depth of 5 *km* beneath the surface. Although the length of the fissure has been constant, about 300 meters say, during the period of the present work, the width gradually increased with a speed of about 1 *cm/day*.[2] It is also observed that both the sides of the fissure were sliding with a counter-clockwise displacement.

3. Method of the resistivity measurement

A four-electrode method is used for measuring earth resistivity. The electrodes are arranged along a straight line on the surface of the ground at an equal distance.

Current being applied to the two external electrodes, a potential difference is produced between the two internal electrodes. Letting V and I be the voltage of the potential difference and the intensity of the current, it is known that the apparent resistivity of the ground is expressed as

$$\rho=2\pi a V/I \,, \qquad (1)$$

1) K. KASAHARA and A. OKADA, *Bull. Earthq. Res. Inst.*, **44** (1966), 335.

2) K. NAKAMURA and Y. TSUNEISHI, *Read at the Monthly Meeting of the Earthquake Research Institute, May 24, 1966.*

where a is the electrode distance.

An L-10 type instrument made by Yokokawa Electric Co., Ltd. was used for the present work. It is a sort of megger consisting of a hand-cranked *a. c.* generator, a commutator, a resistor and a galvanometer. The generator supplies an alternating voltage of about 350 V, the frequency of which is about 65 cycles when rotating the handle at a speed of about 150 *r.p.m.* The resistor dial is made so as to directly indicate $R=V/I$ at an equilibrium state of the circuit when no current is flowing through the galvanometer.

4. Model experiment

A laboratory experiment in a water bath is made in order to study

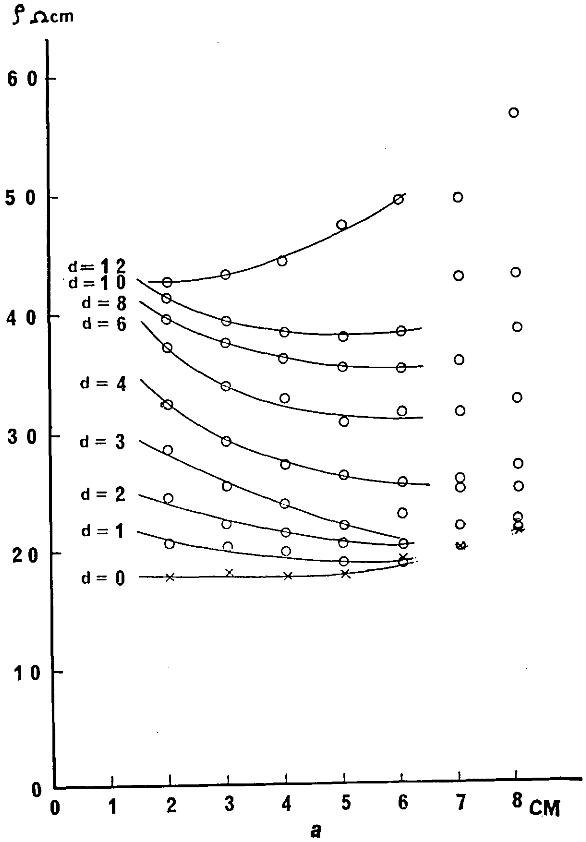

Fig. 2. Relations between the variation of depth of the fissure and that of the apparent electric resistivity. d: depth of the ebonite plate.

the relation between the depth of the fissure and that of the apparent electric resistivity. The size of the water bath is $42\,cm \times 42\,cm \times 15cm$.

A salt solution of proper concentration is made use of in the present experiment. A fissure is simulated by a thin ebonite plate which is insulating. By putting the plate at various depths, an idealized effect of a fissure on electric conduction could be produced.

Relations between the variation of depth of the fissure and that of the apparent electric resistivity obtained in the present experiment are shown in Fig. 2.

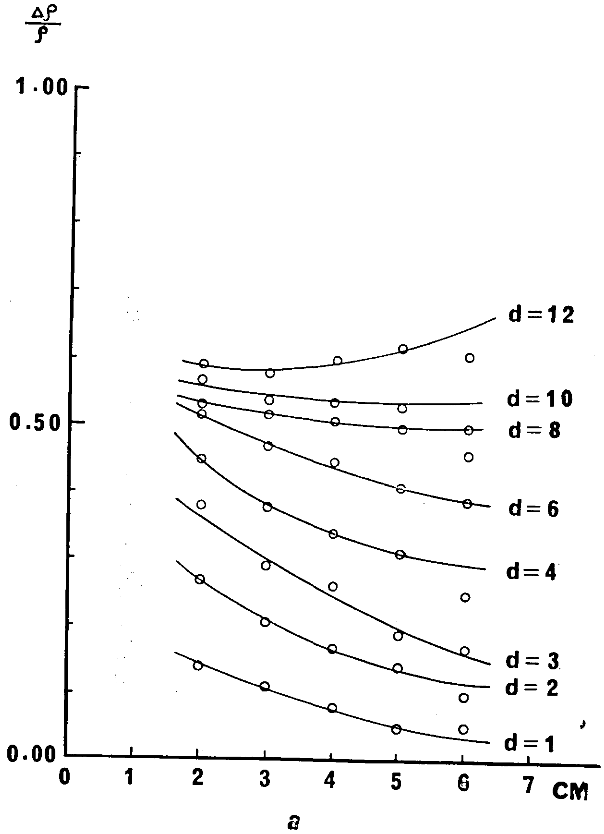

Fig. 3. Relations between the ratios of change in resistivity to its original value and the electrode distance. d: depth of the ebonite plate.

When the ebonite plate is not there, the larger the electrode distance is, the lower becomes the electric resistance. However, the apparent electric resistivity takes on a constant value because of the product of the electric resistance and the electrode distance as can be seen in (1).

When the ebonite plate is there, the apparent resistivity decreases with the increase in the electrode distance because of changes in current path in the solution. When the electrode distance is larger than 6 *cm*, it is observed that the apparent resistivity takes on slightly higher values because of the finite size of the water bath. Moreover, when the depth of the plate is deeper than 12 *cm*, the apparent resistivity seems to be subjected to the influence of the bottom of the water bath. Relations between the ratios of change in resistivity to its original value and the electrode distance are shown in Fig. 3. From these results, it will be concluded that the deeper the fissure is growing, the higher becomes the apparent electric resistivity even in an actual case of ground fissure. These empirical results are important in interpreting the field measurements.

5. Results of the field work

Actual measurements of resistivity were made on the fissured ground in Takehara Village. It was first of all intended to determine the underground structure by an electric prospecting over the area. Fig. 4

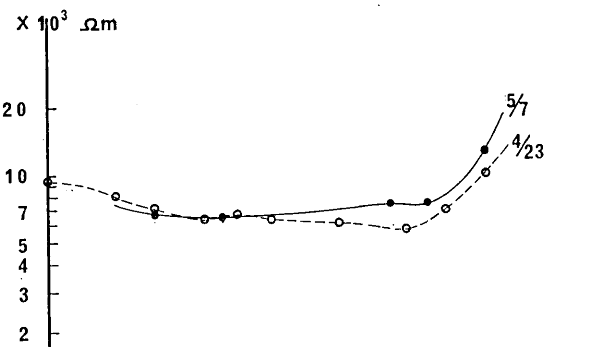

Fig. 4. Apparent resistivity versus the electrode distance.

indicates the apparent resistivity (ρ) versus the electrode distance (a) curve. A most likely interpretation of the curve would be the one as shown in Fig. 5 in which we see that the thickness of surface soil of resistivity $1000\Omega m$ amounts to $1.6\,m$. The second layer of which the depth is estimated as $22\,m$ has a resistivity amounting to $450\Omega m$, so that the composition of the layer would be gravel and underground water. Next comes a layer having a resistivity of $960\Omega m$. Judging from the resistivity value, the third layer seems to be composed of sand and water. These layers are underlain by a basement, of which the lower limit is undetermined, having a high resistivity amounting to $9800\Omega m$.

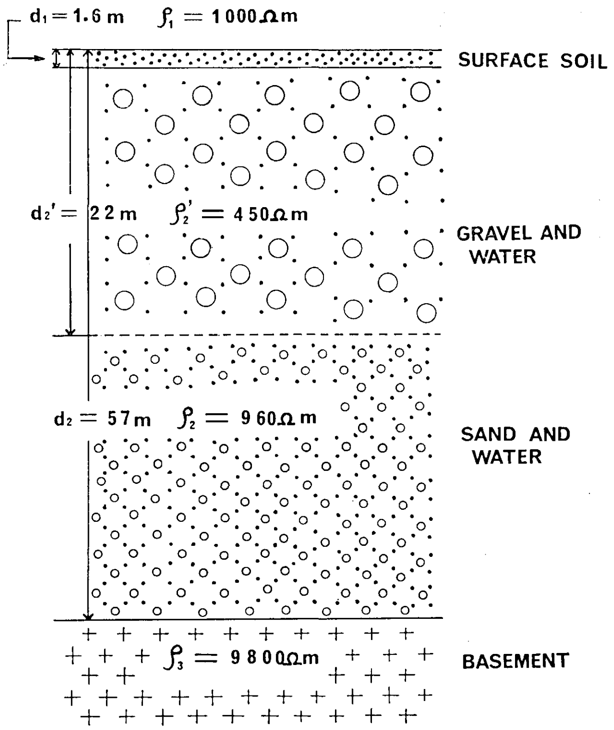

Fig. 5. Underground structure by an electric prospecting.

The author is particularly interested in whether or not the fissures are reaching the basement. It is therefore planned to measure the resistivity with an electrode distance which is large enough to bring forth information at a depth of a few scores of meters. A 90 *m* distance is actually adopted across a fissure, the line connecting the electrodes being perpendicular to the direction of the fissure.

Changes in the apparent resistivity with time as measured by such an electrode distance are shown in Fig. 6. Quite contrary to the author's original idea, the resistivity exhibits extremely complicated changes amounting to 20–30 per cent of its absolute value. As the method of measurement is an established one, it is hard to suppose that the large fluctuations in resistivity are caused by some defect in the measuring technique. No correlation are found between the said changes and earthquake occurrences or rain falls. The only explanation of such large fluctuations in the resistivity would be changes in water content in the underground layers although the author does not know whether or not it is possible to expect such changes in water content.

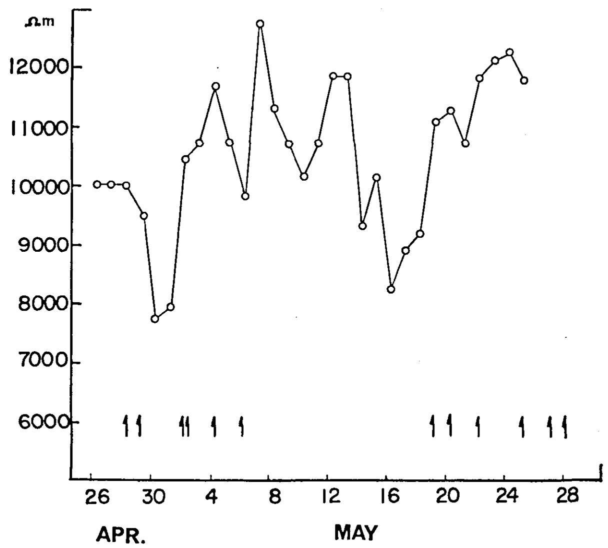

Fig. 6. Changes in the apparent resistivity with time.

The measurements with a 90 *m* electrode distance as described in the above do not bring out the effect of a fissure very clearly. The author is of the opinion that such an effect might be detected by measurements with smaller electrode distances provided the fissure depth is not very large. Measurements of resistivity in the directions either parallel or perpendicular to the fissure trend are made with 40, 80, 120, 160 and 240 *cm* electrode distances.

If a fissure has an insulating effect as has been demonstrated in the model experiment, it is expected that the apparent resistivity in a direction perpendicular to the fissure should be higher than that parallel to the fissure. However, the measurements exhibit contrary results at 40, 80 and 120 *cm* electrode distances as can be seen in Fig. 7 although the difference in apparent resistivity between the two directions seems to decrease at larger electrode distances.

The author suspects that there should be apparent anisotropy in earth resistivity. Such anisotropy is not uncommon in earth resistivity measurement. It is also hard to understand the change in the apparent resistivity with the increase in the electrode distance only on the basis of the model experiment in a uniform medium. Hence it is likely that the effect of the fissure on earth resistivity is not large, if not zero, while the effect of layering could be so large that the major feature of the resistivity versus electrode-distance relations as shown in Fig. 2 would be controlled by it.

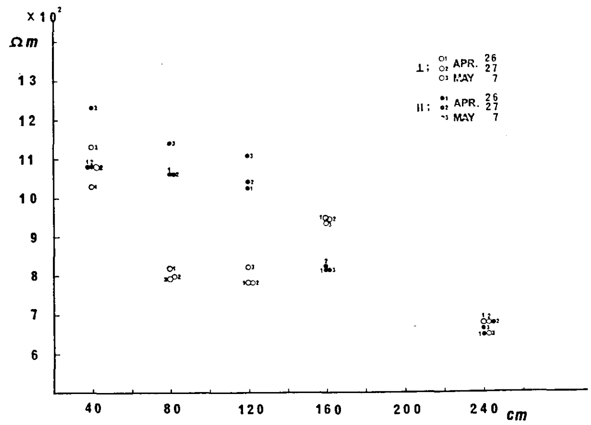

Fig. 7. Apparent resistivity versus the electrode distance.

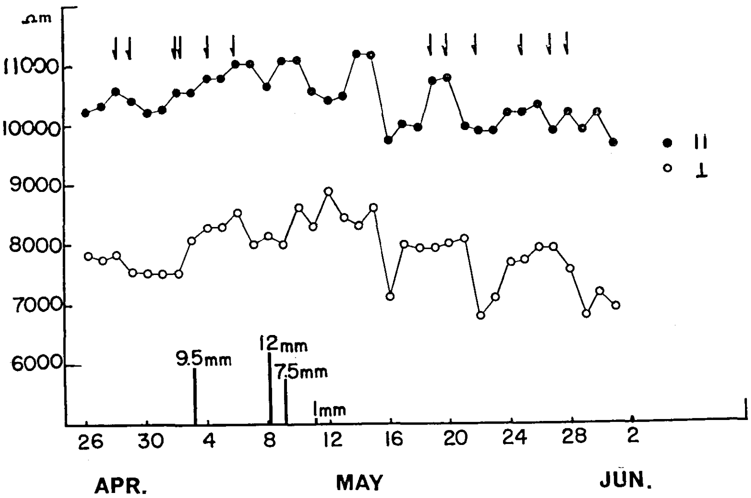

Fig. 8. Changes in the apparent resistivity in the two directions as measured with the 120 cm electrode distance.

Changes in the resistivity in the two directions as measured with the 120 *cm* electrode distance are shown in Fig. 8. The period of measurement is the same as that for the 90 *m* electrode distance measurement which has been already shown in Fig. 6. It is noticeable that the resistivity values in both the directions fluctuate to some extent although the fluctuations are a little smaller than those for the 90 *m* electrode distance measurement. No obvious correlation between the changes in resistivity and either earthquake occurrences or rain falls can be found again. The author does not at the moment have any concrete idea about how to account for the changes.

6. Concluding remarks

The author's original intention of determining the depth of a ground fissure by measuring earth resistivity over a fissured area failed probably because of complicated underground layering and anisotropy in earth resistivity. No workable comparison between the field measurements and the model experiments was possible. To the author's surprise, very large changes in the apparent resistivity were brought out by a series of day-by-day measurements. No marked correlation between changes in the apparent resistivity ($\Delta\rho$) and either earthquake occurrences or rain falls was recognized. $\Delta\rho/\rho$ values sometimes exceeded 0.2 as can be seen in Fig. 6 for the 90 *m* electrode distance measurement although somewhat smaller values are obtained for the short distance measurements.

Y. Yamazaki,[3] who made experiments on changes in the resistivity of sedimentary rocks, discovered a rock sample, a lapilli tuff from Aburatsubo, Kanagawa Prefecture, of which $\Delta\rho/\rho$ exceeds 10^{-2} when the specimen is subjected to a compression of the order of 10^{-4}. A series of resistivity measurements of rocks made by Brace et. al.[4] under a pressure ranging $0.05-10\ Kb$ also indicated fairly large changes in rock resistivity. In the light of these experimental results, high $\Delta\rho/\rho$ values as observed in the actual field this time may have something to do with possible stress changes in the earthquake are although nothing definite can be said at the present stage of investigation.

Acknowledgment

The author would like to express his thanks to Prof. T. Rikitake

3) Y. YAMAZAKI, *Bull. Earthq. Res. Inst.*, **43** (1965), 783.

4) W. F. BRACE, A. S. ORANGE, and T. R. MADDEN, *J. Geophys. Res.*, **70** (1965), 5669.

and Mr. Y. Hagiwara whose constant advice towards the present work has been most valuable, and also thanks Mr. M. Saito of Takehara Village who helped him with measurements.

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82. 松代地震における割れ目と比抵抗

地震研究所 川 田 薫

松代群発地震によつて皆神山方向の扇状地に割れ目群ができた．著者は竹原部落に割れ目群が発生してから4週間，割れ目と比抵抗の相関を調べるために，span を割れ目に垂直な成分と平行な成分にはつて観測した．しかし，複雑な地層と多分電気抵抗の異方性のために，割れ目と比抵抗の間に明瞭な相関は得られなかつたが比抵抗に 20% 程度の大きな変動が観測されたことは驚くべきことである．この比抵抗の変動と地震，雨量の間にも相関は認められなかつた．