# Secular Variation of the Electrical Conductivity Anomaly in the Central Part of Japan

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**Abstract**

Vectors of geomagnetic short period variation are confined in a plane at a given station generally by a conductivity anomaly within the earth. Secular variation of the inclination of the plane deduced from geomagnetic variations observed at Tokyo and Kakioka is given for the period from 1897 to 1970. The range of the variation amounts to more than 30% of the present value. The smallest inclination coincided with the occurrence of the great Kanto earthquake in 1923. Initially the inclination was decreasing, and it increased rapidly after 1923, coming to the maximum around 1940. Since then it has decreased gradually. It suggests a cyclic change with a period of 70–100 years which may be explained by a tectonic motion of the floor of the Pacific Ocean.

## Introduction

Many studies on the electrical conductivity anomaly in Japan have been reported by Rikitake and others. Anomalously large values of vertical component of geomagnetic short period variation are common everywhere in the Pacific Ocean side of the central part of Japan. This is the well-known central Japan anomaly[1]. Detailed investigations[2][3] on the distribution of anomalous vertical component show that some of them may be caused by coast effects due to sea-land distribution. When the effect is excluded, the anomaly is related to heat flow distribution and may be explained by the undulation of upper mantle conducting layer[4].

The vertical component $\Delta Z$ of geomagnetic short period variation relates generally with the other components, $\Delta H$ and $\Delta D$, in a linear equation,

$$\Delta Z = a\cdot\Delta H + b\cdot\Delta D, \qquad (1)$$

at a given station, where the factors $a$ and $b$ are constants for a given period of variation. This relation holds well at many stations in the central Japan anomaly, so that the conductivity anomaly can be represented by the factors $a$ and $b$. Distributions and period-dependencies of the factors have been studied by many investigators.

On the other hand, the change of the factors is scarcely considered. Yoshimatsu[5] has tried to find some changes in monthly mean values of $\Delta Z/\Delta H$ with special reference to earthquake occurrence. The central Japan anomaly is in a well-known seismically active region. His changes are small and short; a few % in a few months for example. Some of them might be apparent because he used $\Delta Z/\Delta H$, as Kuboki[6] pointed out a risk of making error. It might be safe to consider that the distribution of conductivity in the earth crust or upper mantle will not change for a long time. But possibility of a change in the factors still remain, because any observational fact is not reported yet.

In this paper, secular variations of the *a*- and *b*-values will be studied using long continued geomagnetic data at Tokyo (1897–1912) and Kakioka (1913–).

Magnetic observatory in Tokyo (35° 41′N, 139° 45′E) was transferred to Kakioka (36° 14′N, 140° 11′E) at the end of 1912 because of growing artificial disturbances. A significant decrease of the factor is found around 1923 when the great Kanto earthquake occurred. Secular trend rather shows a cyclic change with a period of 70–100 years.

## Data analysis

A conductivity anomaly deduced from the factors, *a* and *b*, in the linear relation (1) may depend not only on the period of geomagnetic variation but also on the type of variation used. For a local or anomalous variation, such as *sfe*, the relation may not hold. Simple and uniform variations are desirable to use in the study of a change in conductivity anomaly. In this meaning, storm sudden commencement *ssc* or sudden impulse *si* is used mainly in this paper. The world-wide distributions of these variations are very simple, but their durations are rather short. Kuboki[6] reported that the rapid decrease of the *a*-value in the short period side. Here, durations of *ssc* or *si* are divided into four parts, 1–3, 4, 5 and 6 minutes. The *a*- and *b*-values calculated

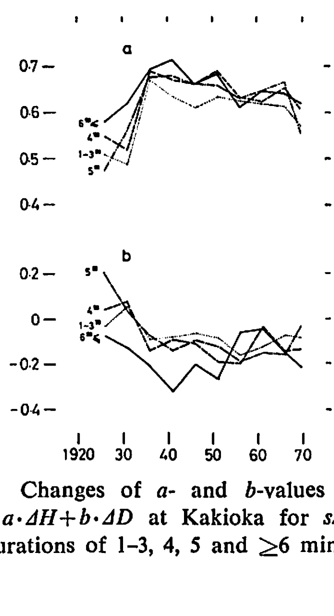


Fig. 1 Changes of *a*- and *b*-values in $\Delta Z = a\cdot\Delta H + b\cdot\Delta D$ at Kakioka for *ssc* with durations of 1–3, 4, 5 and $\geq$6 minutes.

by the method of least squares are shown in Fig. 1 for each 5-year-period from 1924 to 1968 and for 2 years 1969–70.

Detailed analyses are able to be done only for the data after 1924, because original magnetograms in earlier years were burned at Tokyo by the fire which followed the great Kanto earthquake on Sept. 1, 1923. Lists of *ssc* and *si* observed since 1924 have been published in the Observatory Report[7] and Yokouchi's paper[8]. Amplitudes of three components $\Delta Z$, $\Delta H$ and $\Delta D$ and durations of $\Delta H$ in these lists are used in the present analysis. Generally durations of each component are slightly different each other. This may cause errors and increase the statistical deviation. But it seems to be trivial to deduce general trend of change such as secular variation. Much importance being attached to exclusion of subjectiveness, any improvement in the original data is not taken into consideration except that extremely deviated values are excluded by a statistical test.

In Fig. 1, all of $a$-values show similar trend of change. Difference between each duration is unimportant to see secular variation. The $a$-value was small in 1920's. It came to a maximum in 1930's and then decreased gradually. The decrease is still continuing. The total range of the change is large. It cannot be explained by any error in the data analysis. On the other hand, determination of $b$-value may include more error than $a$-value because horizontal vectors of *ssc* or *si* direct nearly northwards and do not change so much from the direction. Nevertheless, similar trend of change in $b$-value is found for all of the duration, particularly for 1–3, 4 and 5 minutes.

The linear equation (1) means that vectors of geomagnetic variation are confined in a plane at a station (Fig. 2). The plane can be represented by several ways, such as Parkinson's Wiese's and Kuboki's vectors. Here the upward normal is used. The angles $\theta$ and $\varphi$ of the normal in the figure will determine the plane. The angles are given by the next equation,

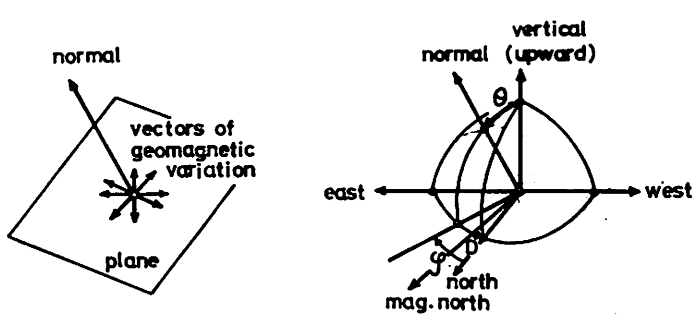


Fig. 2 Plane in which vectors of geomagnetic variation are confined. Direction of the upward normal of the plane is expressed by the angles $\theta$ and $\varphi$.

$$\tan(\varphi - D) = b/a, \tag{2}$$

$$\tan\theta = \sqrt{a^2 + b^2} \tag{3}$$

where $D$ is the mean declination at the station. The $\sqrt{a^2+b^2}$ represents the inclination of the plane.

As $b$-values are small, the inclination of the plane is not affected so much by the $b$-value. Errors in determining $b$-values, even if they are larger than those of $a$-values, will be trivial in considering a change of the inclination which is more than 30%. Most severe change of the inclination in early years are shown in Fig. 3. Mean slopes of the plane for the duration 1–5 min. are shown by full lines for the first 10 years, 1924–33 and by broken lines for the second 10 years, 1934–43. Regardless of the

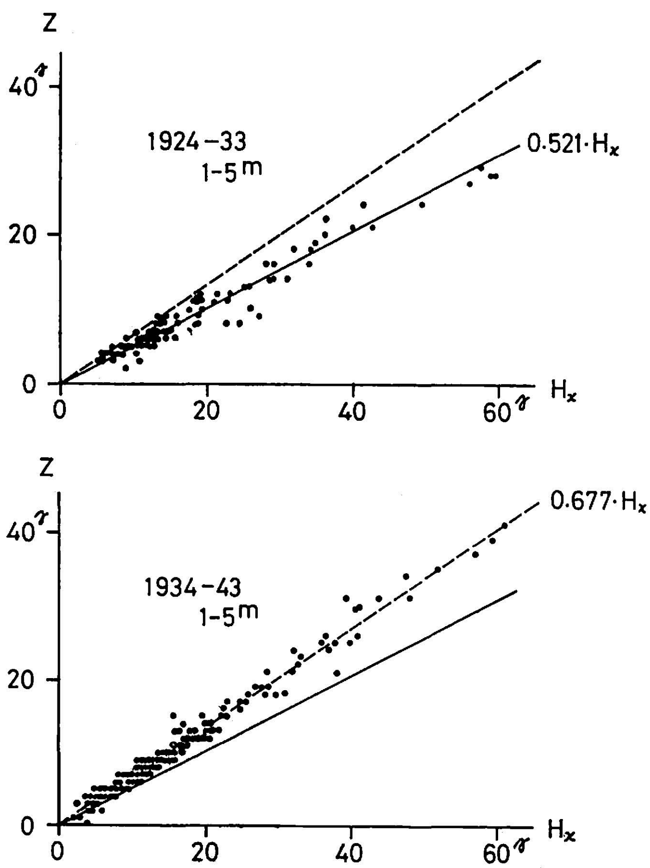


Fig. 3 Mean slope of the plane in which vectors of geomagnetic variation are confined at Kakioka for 1924–33 (fulll line) and for 1934–43 (broken line). Each dot represents the observed one where $Z$ is the vertical component and $H_x$ the horizontal component in the direction of the normal of the plane.

division of 5 years and the duration, *a*- or *b*-values are averaged. Each dot represents the observed value of *ssc* or *si*, where $H_x$ is the horizontal component in the horizontal direction of the normal of the plane. The figure shows the fitness of the calculated plane. Though the dots are rather scattered, two planes are separated clearly. One cannot be replaced by the other.

Original magnetograms before 1924 were lost as mentioned above, and any list of *ssc* or *si* is not avairable. But some copies of magnetogram on disturbed days remain fortunately. Amplitudes and durations of *ssc* and *si* are measured on the copies by the present author for the period from 1897 to 1923. Short period variations of the other kind, such as geomagnetic bay, are also used supplementarily, because the number of avairable *ssc* or *si* is rather small.

For the period of observation at Kakioka from 1913 to 1923, the duration is divided into two parts, 1–5 and 6 minutes. Calculated *a*- and *b*-values are shown in Fig. 4 together with the values after 1924. The period is divided into two parts, 1913–17 and 1920, because none of magnetogram copy is avairable for the years, 1918–19

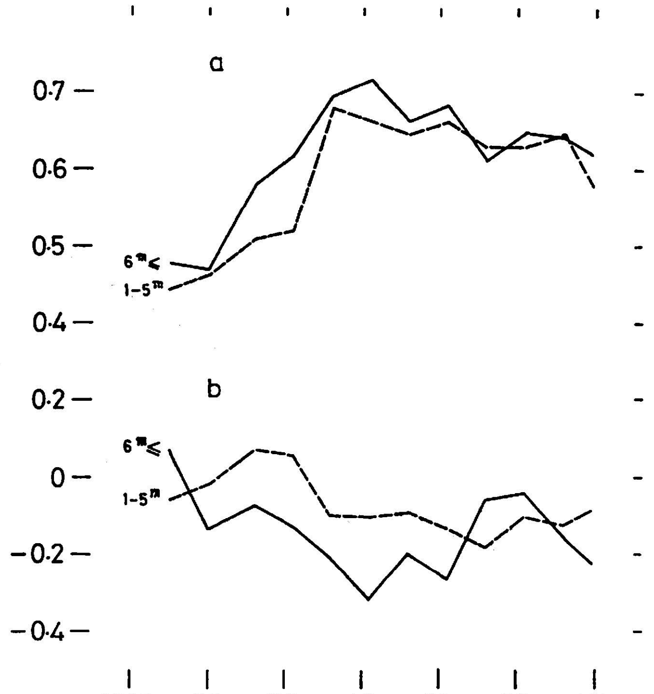


Fig. 4 Change of *a*- and *b*-values in $\Delta Z = a \cdot \Delta H + b \cdot \Delta D$ at Kakioka during the full period of 1913–70 for variations with durations of 1–5 and $\geq 6$ minutes.

and 1921–23. The values for 1–5 minutes in the period from 1924 to 1970 are averages of those for the durations 1–3, 4 and 5 minutes.

For the Tokyo observation, geomagnetic variations of durations larger than 6 minutes only are used because of erroneous copies for very rapid variation. General trends of secular variation seem to be similar for each duration range as is shown in Fig. 1 and Fig. 4, at least in $a$-values. And the period-dependency[6] shows uniformity in longer side than 6 minutes. These will permit to use durations larger than 6 minutes to deduce secular variation.

On the other hand, the station Tokyo is far from Kakioka, being 70 km apart to the south-south-west. Different locality should bear difference in $a$- and $b$-values. The true difference between Tokyo and Kakioka is not known. In and around the big city Tokyo, natural magnetic field is disturbed severely now by artificial fields. However the distribution of $\Delta H$ and $\Delta Z$ of geomagnetic variation has been studied by the present author[9] with special reference to surface currents in the sedimentary laryer of the Kanto district which includes Tokyo and Kakioka. According to his consideration, effects of the supposed sedimentary layer which is shown in Fig. 5 are calculated. The effect on $\Delta Z/\Delta H$ is about 10% for the mean duration of used variations. Regardless of the difference in the direction between the axis of the sedimentary layer and the observed variation vector, the calculated correction is added to the $a$-value of Tokyo observation. Corrected $a$-values are shown by full line in Fig. 6 together with the Kakioka's values since 1913. Uncorrected values are also indicated by thin dotted

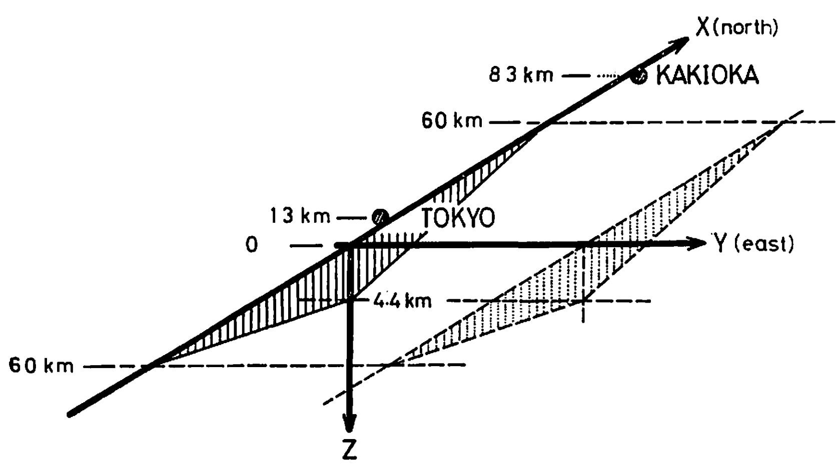


Fig. 5 Supposed sedimentary layer in the Kanto district. Vertical section of the layer is shown by thin vertical lines. It extends nearly eastwards and westwards. Its resistivity is 4 ohm·meter and the ratio of electric field to horizontal magnetic field is 0.47 mV/km/γ for 2000 sec.

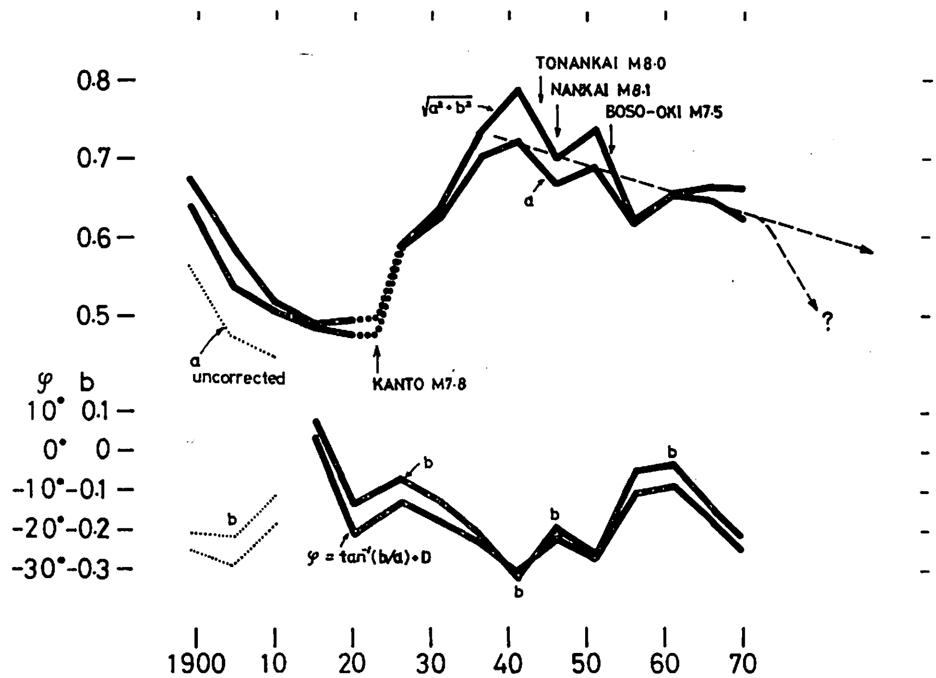


Fig. 6 Secular variation of $a$- and $b$-value in $\Delta Z = a \cdot \Delta H + b \cdot \Delta D$, $\tan\theta = \sqrt{a^2+b^2}$ and $\varphi = \tan^{-1}(b/a) + D$.

line. Divided periods for which $a$- and $b$-values are determined are 1897–1901, 1902–07 and 1908–12. As to $b$-values, uncorrected ones only are shown because the correction is seriously affected by differences between the axis of the sedimentary layer and variation vectors. Inclinations of the plane, $\sqrt{a^2+b^2}$, and azimuths of the normal, $\varphi$, are also shown in the figure, where uncorrected $b$-values are used.

Both of the $a$-value and the inclination $\sqrt{a^2+b^2}$ show a very similar change for the total period from 1897 to 1970. As $b$-values are small, there is no need of considering the contribution from a change of $b$-value in deducing secular variation of the inclination of the plane.

## Discussion

A significant secular variation of the conductivity anomaly is found in the central part of Japan as is shown in Fig. 6. An explanation of the central Japan anomaly has been given by Rikitake(4) and Uyeda and Rikitake(10). According to them the anomaly is connected to the structure of southwestern Japan and can be explained by the undulation of upper mantle conducting layer (Fig. 7) which is deduced from heat flow distribution. Since any information on change in the upper mantle is not avairable

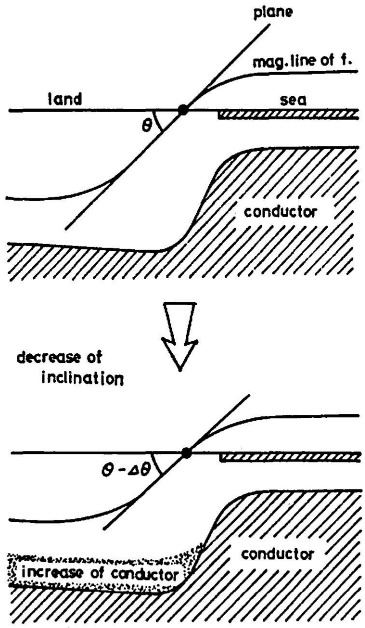


Fig. 7 Rikitake's model of the central Japan anomaly of electrical conductivity (upper) and a supposed increase of conductor when the inclination of the plane in which vectors of geomagnetic variation are confined is decreased (lower).

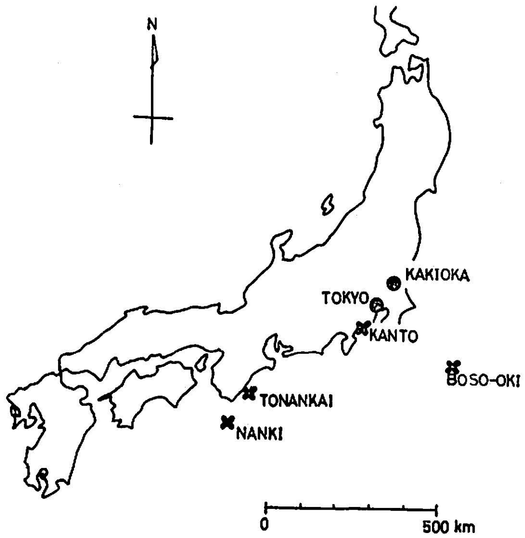


Fig. 8 Map showing the observing station (black circle) and the epicenter of great earthquake (cross).

yet, great earthquakes which occurred in the Pacific Ocean side of the southwestern Japan with a magnitude larger than 7.5 are shown by arrows in Fig. 6 as a reference instead. The Kanto earthquake in 1923 is the nearest to Tokyo or Kakioka (Fig. 8). The Tonankai (1944) and Nankai (1946) earthquakes are far, being more than 500 km apart from Kakioka. More farther ones are omitted. The Boso-Oki earthquake is rather near, but its magnitude is the smallest among the indicated four.

A remarkable decrease in inclination of the plane in which vectors of geomagnetic variation are confined seems to coincide with the occurrence of the Kanto earthquake. For a few years around the occurrence the detailed change is not known because no magnetogram is avairable. A supposed change is shown by dotted line in Fig. 6. The inclination of the plane continued to decrease from the earliest years of observation and attained to the minimum at the Kanto earthquake in 1923. The rate of decrease became gradually slow. Though some doubts of the continuation in data from Tokyo to Kakioka still remain, the decrease in the early years is clear as it is shown by uncorrected $a$-values. After the occurrence of the earthquake the inclination increased rather rapidly and came to a maximum at about 1940. Since then it has continued to decrease gradually. This suggests some process of accumulation and release of energy or so.

Significance of small change in the last decreasing stage is not certain, though some apparent relations to the indicated earthquake occurrences are found. Regardless of the small change, the inclination decreases linearly. If the trend is extended to future, the inclination will reach again the same minimum value about 100 years from 1923. A cyclic change with a period of about 100 years may be expected. But the present value of the inclination has come already to the value at the earliest years of the observation. If the decreasing rate in future will be the same as those in early years from 1897 to 1923, the next minimum will come earlier. In this case 70 years will be the period of cyclic change.

No other evidence is known on cyclic change of the deeper part of the earth. And the observation period of the present result is too short to deduce such a change with a long period. But a periodic deformation of the earth crust with a period of 100 to 150 years in the southwestern part of Japan has been mentioned with special reference to earthquake occurrence(11). Recent hypothesis of plate tectonics may lead us to consider that a movement of the floor of the Pacific Ocean drags the earth crust and then the stored energy is released by a large earthquake 100 years or so after. If this process can cause also an increase of electrical conductivity in the non-conducting layer of the upper montle (Fig. 7), the present result of secular variation may get a theoretical stand. Unfortunately mechanism of such a change in conductivity within the earth is not known yet. Nevertheless the change in inclination of geomagnetic variation vector is clear and it can be explained only by a change in conductivity. In the external magnetic field there is no evidence of such a large change in its character as causes the observed secular variatian.

## Reference


(1) Rikitake, T.: Outline of the Anomaly of Geomagnetic Variations in Japan, J. Geomag. Geoelec., **15** (1964), 181–184.

(2) Sasai, Y.: Anomalous geomagnetic variation in the central part of Japan, Proc. Conductivity Anomaly Symp. editted by Rikitake (1969), 43–55.

(3) Sasai, Y.: Spatial dependence of short-period geomagnetic fluctuations on Oshima Island (2), Bull. Earthq. Res. Inst., 46 (1968), 907–926.

(4) Rikitake, T.: The undulation of an electrically conductive layer beneath the islands of Japan, Tectonophys, 7 (1969), 257–264.

(5) Yoshimatsu, T.: Result of Geomagnetic Routine Observations and Earthquakes, Memo. Kakioka Mag. Obs., **11** (1963), 71–83.

(6) Kuboki, T. and H. Oshima: The anomaly of geomagnetic variation in Japan (Part 3), Memo. Kakioka Mag. Obs., **12** (1966), 127–198.

(7) Series of the Report of the Kakioka Magnetic Observatory, Geomagnetism and the Report of the Geomagnetic and Geoelectric Observations, Rapid Variations published annually by the Kakioka Magnetic Observatory.

(8) Yokouchi, Y.: Principal Magnetic Disturbances at Kakioka, 1924–1951, Memo. Kakioka Mag. Obs., 6 (1953), 204–248.

(9) Yanagihara, K.: Magnetic fields caused by earth surface currents in Kanto district, Memo. Kakioka Mag. Obs., **14** (1971), 79–87.

(10) Uyeda, S. and T. Rikitake: Electrical conductivity anomaly and terrestrial heat flow, J. Geomag. Geoelec., **22** (1970), 75–90.

(11) Nagata, T.: Tectonomagnetism, Trans. General Sci. Assem. Madrid, Spain, 1969, IAGA Bul. No. 27, 12–43.

# 電気伝導度中部日本異常の経年変化

柳　原　一　夫

ある一つの観測点における短周期地磁気変化のベクトルは一般的に一つの面にのっている。この面の地域分布あるいは変化周期に対する依存性などは相当多く研究されているが，時間的変化については殆んど調べられていない。この論文では東京（1897–1912）と柿岡（1913–　）の観測を使って長い期間の経年変化を求めた。その結果30%にも達する案外大きな変化のあることがわかった。これは観測誤差によるものとは考えられない。面の傾斜が最小になる時期は関東大地震（1923）と一致し，それまで減少してきていたものが地震後比較的急激に増加して 10 年位後に最大となってその後除々に減少している。この減少の傾向がそのまま持続するとすれば関東大地震から 100 年後にまた同じ極小値に到達する。また現在の値はすでに観測初期の値に達しているのでその後が初期と同様の経過をたどるとすれば 70 年後となる。これらのことは 70–100 年位の周期的変化を予想させる。プレートテクトニックスの観点から説明されるものかもしれない。