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Anomalous Secular Variation of Geomagnetic Total Intensity In Chugoku District, Japan

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Abstract

In 1971 Geomagnetic surveys in the Chugoku district have been carried out by using a portable proton precession magnetometer. The ordinary method of epoch reduction to eliminate non-local changes in the geomagnetic field has been slightly modified by using the data obtained at the Tottori Micro-Earthquake Observatory, where an observation of geomagnetic total intensity has been carried out since 1967 by means of a proton precession magnetometer.

Secular variations of geomagnetic total intensity during a period from 1965 to 1971 at various stations were examined comparing the available data obtained by the Geographical Survey Institute during the period from 1965 to 1966.

The results show that there may exsist marked anomalous secular variations in the Chugoku district, whose features are fairly systematic. Some correlation between the areas having the anomalous secular variation and the geomagnetic anomalous regions has been recognized. This suggests that the anomalous secular variation in the Chugoku district may be caused by the piezomagnetic effect or the crustal movements due to the horizontal compression of E-W trend in Southwest Japan.

1. Introduction

Local changes in the geomagnetic field associated with an occurrence of an earthquake were often reported by many investigators[1]. But Rikitake[2] pointed out that such local changes were sharply decreasing in their magnitude as years advanced, and suggested that the reason was the secular improvements of the field measuring techniques with time as well as from the consideration of the elimination of non-local change in the geomagnetic field. With the year-by-year progress in the measuring techniques and further investigations for the method of the elimination of non-local changes, the detectable values of the geomagnetic change regarded as the seismomagnetic effect may be expected to fall in a 5–15γ range. According to Nagata and Kinoshita's study[3] on the relation between magnetic susceptibility (χ) and remanent magnetization (J) of rocks and compression, the anomalous annual change in the geomagnetic field is estimated to be in the order of $2\sim3\gamma$ per year.

As part of the earthquake prediction research program in Japan, a proton precession magnetometer has been set up since 1967 at the Tottori Micro-Earthquake Observatory, which is situated on the Japan sea side of the Chugoku district, in South-western Japan. As the proton precession magnetometer is free from both the secular change of instrumental constant and the drift of base line, we can easily make precise observations for a long period within an accuracy of $\pm1\gamma$. Hence it seems that we can easily detect the anomalous change regarded as the seismo-magnetic effect, if it exsists. But a troublesome problem is still left: a method of elimination of non-local changes in the geomagnetic field.

Recently energetic investigations on the electric conductivity anomaly in Japan revealed the fact that there were remarkable local characteristics in the feature of geomagnetic changes. Since it is no easy matter to make an accurate normalization by the ordinary method, it has been suggested by Rikitake[4] to use a weighted difference technique to compare the total intensities of the geomagnetic field between two stations at a moderate distance.

The present writer also examined the question in a prevoius paper[5] concerning to the method of elimination of non-local changes, the secular change of the total intensity in the geomagnetic field at Tottori, and the relative secular change at Tottori with reference to the Kakioka Magnetic Observatory (the geomagnetic reference station in Japan) during the period from 1967 to 1969, and obtained the following conclusions:

1) There are the local characteristics in the phase difference between the change of the vertical component and that of the horizontal one of the geomagnetic daily variation (Sq), so that the total intensity has not a few local anomalies in phase and in amplitude. It may be therefore desirable to make use of the daily mean value or the mean value for the interval of a few hours at night when the difference of the geomagnetic toatl intensity between two stations is used to eliminate non-local changes.

2) Geomagnetic total intensity at Tottori has been apparently gradually decreasing with a almost constant rate of 22.5γ/year. However a slight annual change has been recognized in the rate of monthly mean variation.

3) It is seen that this variation is contaminated by some magnetic disturbances, which are caused by the ring current occurring at the time of magnetic storms. In order to elimanate these disturbances Dst correction to daily mean values is made by using the Sugiura's Dst indices, so that the rate of the secular variation is corrected to be -31.7γ/year.

4) In spite of the long distance, amounting to 541 km, between Tottori and Kakioka, the difference of daily mean value proves to be a fairly stable value. It may be due to the reason that the latitude and the inclination of two stations are almost equal. By using such daily mean values it can be concluded that the relative secular variation between Tottori and Kakioka is about -1.6γ/year. This value is also supported by the results obtained in the geomagnetic surveys done in Japan by the Geographical Survey Institute.

In order to examine the latest anomalous secular variations in other regions of the Chugoku district, geomagnetic total intensities were observed with a portable proton precession magnetometer (ZEONIX magnetometer) during the period from March to April, 1971 on the first order and the second order magnetic stations set up by the G.S.I. covering an area of about 200 km in length and 50 km in width. Among these stations, the first order magnetic surveys were repeated over a long period of time by the G.S.I. and it was reported that there were marked anomalies of secular change of the order of $3\text{–}4\gamma$/year at the areas of Hamada and its neighbour, which are situated in the west part of the Chugoku district. Anomalous secular change means that there is an unusually large deviation from the geomagnetic secular variation as observed at the Kakioka Magnetic Observatory.

The present observation has been carried out at the areal density of about one per 20 sq. km and it may be expected that more detailed information about the features of the secular variation in the Chugoku district can be obtained.

Temporary secular variation in these regions are estimated by comparing the present data with ones already obtained at every station by the G.S.I. during a period from 1965 to 1966, and it is concluded that there were interesting marked distributions of anomalous secular variation in the Chugoku district.

2. Observation

The portable proton precession magnetometer which was used can observe a total intensity in the geomagnetic field to the extent of 1γ. It has become clear that a mean value of total intensity observed by the portable magnetometer for 20 observations with a time interval of one minute is reliable to the extent of $\pm 1\gamma$ according to the comparison with another, more precise proton mangetometer, whose accuracy is about $\pm 0.5\gamma$.

As a rule, observations at every station were made one a minute for an interval of twenty minutes after 16h (local time), the reason for which is described later. On the other hand at the Tottori Micro-Earthquake Observatory (To), which is assigned as the sub-reference station in present surveys, continuous observations were made simultaneously every minute by another proton magnetometer.

Observations were also made at the height of 1.5 m each at the first order and second order magnetic stations, where granite bench marks were buried. The feature of geomagnetic changes at almost every station closely resembled that of the To station. The standard deviation around the mean value of 20 observations at each station was within the range of about $1 \sim 2\gamma$.

3. Epoch reduction

As mentioned in the introduction, the accuracy of the magnetometer having been remarkably raised lately, reliability of the observed value is within the limits of $\pm 1\gamma$, but it can not be said that the accuracy of the epoch reduction is sufficient to detect very little local anomalous changes. Epoch reduction means here that the observed values at every station are used to reduce to normal values that are free from non-local changes by using the observed value at the reference station.

The G.S.I. is used to make the epoch reduction for magnetic surveys using the observed value at the Kakioka Magnetic Observatory (Ka), and also to get a reduced value at each station. This is bsaed on the assumption that the geomagnetic transient variation at some station is nearly equal to that at Ka station.

Though this assumption is acceptable as a first approximation, it may be invalid when a precise secular variation in the geomagnetic field is discussed. Because the reduced value obtained by such an epoch reduction is not free from contamination by errors owing to the local irregulality of the transient variations in the geomagnetic field, which is supposed to be mainly caused by electromagnetic induction in the earth's crust and mantle.

Considering the above errors in detail, they may be divided into two sources. One arises from the local amplitude difference in the change of a comparatively short period such as the geomagnetic bay type variation or similar changes. Another is due to the phase difference of Sq daily variation. In the latter case, the phase difference is most strongly affected by the path of the center of overhead equivalent current system for daily variation as studied by Mori and Yoshino[6]. The former does not necessarily depend on the distance between the observed station and the reference station, but on rather conductive anomalies. On the other hand the latter depends on the difference of the latitude and longitude between the two stations.

The G.S.I. is used to make the first order magnetic observation through a day, and uses the daily mean value to get the reduced value. On the other hand for the second order magnetic survey, the G.S.I. makes use of observations taken only four times an hour, as a rule taken after 16h (local time), and uses the mean value of them. According to the detailed study by Tajima[7], the accuracy of the epoch reduction is regarded in the case of the first order survey as ± 3–4γ, and the second order survey as ± 7–8γ. As a practical method, the G.S.I. is used to obtain the reduced value by making the epoch reduction by the following formula,

$$M_p^r(t)=M_p(t)+M_k(t_0)-M_k(t) \tag{1}$$

where $M_p^r(t)$ and $M_p(t)$, respectively denote the reduced value of a geomagnetic element and the observed value at an arbitrary time t at p station, $M_k(t_0)$ is the normal value at the epoch ($t=0$) and $M_k(t)$ is the observed value at the Ka station.

Here let us modify (1), assigning M to F, the geomagnetic total intensity, in order to utilize the observed value at To station,

$$F_p^r(t)=(F_p(t)-F_T(t))+(F_T(t)+F_k(t_0)-F_k(t)) \tag{2}$$

where $F_T(t)$ is the observed value at the To station.

Seeing the second term on the left of (2), it may be regarded as the reduced value at the To station. Therefore (2) can be rewritten as;

$$F_p^r(t)=(F_p(t)-F_T(t))+F_T^r(t) \tag{3}$$

where $F_T^r(t)$ is the reduced value at the To station.

The value of $F_T^r(t)$ is free from the transient variations if it can be obtained by the observation over long intervals, for example one month. The variation of $F_T^r(t)$ versus year is shown in Fig. 1. It may be said from this figure that the variation of

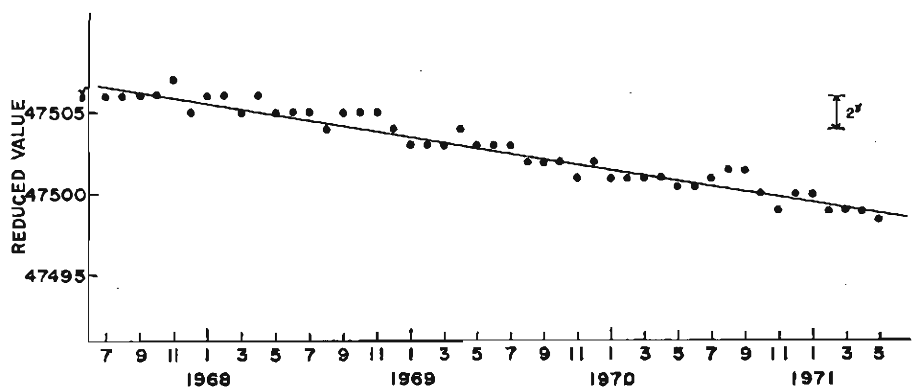

Fig. 1. The relative secular variation of the reduced value in the geomagnetic tatol intensity ($F_T^r(t)$) at the Tottori Micro-Earthquake Observatory referring to the Kakioka Magnetic Observatory.

$F_T^r(t)$ is fairly linear for long intervals and that it's gradient is -2.1γ/year with a standard deviation smallar than 0.1γ/year, which is calculated by means of the least squares technique. The value of $F_T^r(t)$ can be, therefore, easily obtained with the accuracy of more than $\pm 1.0\gamma$ whenever we want.

But the first term on the left of (3) is a much disputed question. It is no easy matter to estimate the errors in it because the fine distribution of local amplitude and phase anomalies in the geomagnetic changes are not clear. However it may be maintained that the errors of the first term are less than that of $(F_p(t)-F_k(t))$ for the following reasons, as far as the Chugoku district is concerned.

First, the Ka station is under the influence of the Central Japan Anomaly of electric conductivity, but the To station and other regions of the Chugoku district have not such a remarkable conductivity anomaly. Second, the phase difference anomaly between $F_p(t)$ and $F_T(t)$ is smaller than that between $F_p(t)$ and $F_k(t)$ in the Chugoku district.

This is also supported by the results obtained by the preliminary observations which were carried out at Matsue and Tōjyō in 1968, which were about 90 km from Tottori, for an interval of about one month each. In these observations it became clear that there was a slight amplitude anomaly in the transient change of short period at each station comparing with the change at To station, the amplitude ratio being in the order of less than 1.1. The errors caused by the phase difference anomaly seemed likely to be almost negligible if observations were made at the time, when the daily variation (Sq) was small, for example after 16h.

In order to see reliability on the mean value of the observation of short time intervals, some examples of the difference of mean values between two stations (Matsue-Tottori and Tōjyō-Tottori), which were obtained by 20 observations at one minute

Table 1. Differences of geomagnetic total intensity between two stations comparing the use of mean values of 20 minutes interval with that of daily mean values.

	Matsue-Tottori	Tōjyō-Tottori
Difference obtained from mean values of 20 minutes interval	S.D $-32.2\gamma\pm1.1$	S.D $160.7\gamma\pm0.9$
Difference obtained from daily mean values	$-31.7\gamma\pm1.1$	$160.7\gamma\pm0.7$

intervals i.e., 16h00 m–16h19 m, 18h00 m–18h19 m and 20h00 m–20h19 m, were calculated using about 30 sets of data for 10 days as shown in Table 1. The difference of daily mean values between the same two stations are also shown in the same table. As far as the Chugoku district is concerned, it can be said from the table that even if the observations are made in an interval of short time the accuracy of reduction may be expected to be well satisfied provided the distance between the observed station and the sub-reference station is comparatively near.

Finally it is ascertained that with the use of the value of $F_T^r(t)$ and the difference of mean values of 20 observations with a time-interval of one minute the epoch reduction may be made with an accuracy of more than $\pm$2–3γ.

The reduced values at every station calculated by the present method are shown in

Table 2. Results of observation of total intensity reduced to 1960.

No.	Station	Location: Latitude	Location: Longitude	Total intensity (F): reduced value G. S. I	Date	reduced value Kyoto Univ.	Date	secular variation
				γ		γ		γ/year
467	Wakasa	35°17'.4	134°26'.7	47332	1966. Jul. 5	47318	1971. Mar. 18	−3.0
468	Saji	35 19.6	134 7.3	47474	9	47489	18	+3.2
469	Shikano	35 28.5	134 3.3	47693	6	47700	18	+1.5
470	Misasa	35 19.0	133 49.7	47472	16	47459	19	−2.8
471	Nakayama	35 29.8	133 35.8	47802	15	47795	22	−1.5
473	Ebi	35 17.2	133 30.6	47515	19	47503	21	−2.6
474	Kurosaka	35 11.1	133 23.2	47749	20	47736	21	−2.8
475	Yokota	35 11.0	133 6.4	47691	25	47689	Apr. 9	−0.4
476	Daito	35 18.9	132 58.4	47641	24	47645	8	+0.9
477	Hinomisaki	35 25.6	132 37.9	48197	Aug. 7	48181	8	−3.4
479	Higashi Susa	35 13.9	132 44.6	46331	4	46317	11	−3.0
480	Ōta	35 12.9	132 28.9	47808	6	47787	11	−4.5
481	Ōchi	35 3.2	132 38.9	47883	8	47875	10	−1.7
483	Takahara	34 53.4	132 33.4	47779	13	47779	11	0.0
484	Hinuki	34 52.9	132 21.5	48308	12	48287	11	−4.5
485	Toji	35 2.2	132 18.3	48149	14	48132	11	−3.6
510	Kakei	34 35.1	132 17.7	47550	Oct. 13	47543	12	−1.6
512	Chiyoda	34 40.3	132 32.4	47630	10	47617	12	−2.9
513	Kabe	34 32.2	132 31.8	47563	9	47552	12	−2.4
520	Miyoshi	34 48.3	132 51.4	47759	1965. Oct. 7	47754	10	−0.9
522	Yuki	35 2.2	133 7.5	48216	10	48197	10	−3.5
530	Tetsuta	34 56.1	133 27.3	47629	Sept. 19	47607	9	−4.0
532	Ochiai	35 1.4	133 45.1	47391	13	47380	Mar. 20	−2.0
533	Kamogawa	34 51.5	133 48.8	47307	12	47289	20	−3.3
583	Tsuyama	35 4.0	134 0.5	47340	5	47330	20	−1.8
584	Nagi	35 7.0	134 10.9	47200	7	47191	20	−1.6
90	Tōjyō	34 56.4	133 12.2	47894	1966. Jul. 19	47890	Apr. 9	−0.8
3*	Kurayoshi	35 21.7	133 52.8	47359	1968. Nov. 27	47353	Mar. 19	−2.3

Table 2 with ones obtained by the G.S.I.. These values are reduced to the following standards:

1. epoch of reduction — 1960.0
2. reference observatory — the Kakioka Magnetic Observatory
3. epoch values of reference observatory — $F_k(t_0)=46122\gamma$

4. Anomalous secular variation in the Chugoku district

The geomagnetic secular variation of total intensity is calculated by the following formula assuming that the variation has been linear.

$$\Delta F_p=(F_p^r(t_2)-F_p^r(t_1))/(t_2-t_1), \qquad (4)$$

where ΔF_p is the relative secular variation at p station referring to the secular variation at Ka station. $F_p^r(t_1)$ and $F_p^r(t_2)$ are the reduced values at p station obtained by repeated observations at $t=t_1$ and $t=t_2$.

Apparent geomagnetic secular variations at every station in the Chugoku district are shown in the last column of Table 2. They are calculated by the above formula using the reduced values at every station obtained by the present method described in the last subsection as well as ones obtained by the G.S.I. about 5 years ago.

From Table 2, it can be said that most regions in the Chugoku district tend to negative secular variations with a few exceptions and that as far as the present data are concerned there exist anomalous stations having the large secular variation. But it can not be discussed in detail that such anomalies can be accidental or physically meaningful as the method of the reduction and the observation are different from each other.

In order to see the fine local features of secular variation in the Chugoku district, the relative secular variation at every station referring to To station are calculated by substracting the secular variation at To station from ones at every station, assuming the value of secular varaition at To station as the standard one (-2.1γ/year) in the Chugoku district. Results are expressed by the contour shown in Fig. 2. Some systematic distribution of the secular variations are seen in Fig. 2. It can be noted that there exsists remarkable contrast in the zone of the positive secular variation and in that of the negative. And yet every zone, whose figures show the feature of NNE–SSW trend, seem to be distributed alternately, in the east-west direction. Examining the pattern of geomagnetic anomalies in the Chugoku district, positive anomalous areas seem to make a row as shown in Fig. 3 as well as the distribution of the secular variations. Some correlation between the areas having the anomalous secular variation and the geomagnetic anomalous regions can be seen.

It is no easy matter to make clear above correlation physically only from the present data. Huzita[8)] showed the structural elements of the Quaternary crustal movements named "Rokko Movements" in Southwest Japan from the neotectonical studies. According to them, it can be suggested that the axes of the anticlinal uplifts and the synclinal depressions due to foundation folding run in the direction of NNE–SSW and that Southwest Japan has been under the horizontal compressive state of E–W trend, which is also confirmed from studies of focal mechanism of microearthquake by Kishimoto et al[9)]. Considering above, it may be said that the secular variations in the Chugoku district are associated with the piezomagnetic effect or the crustal

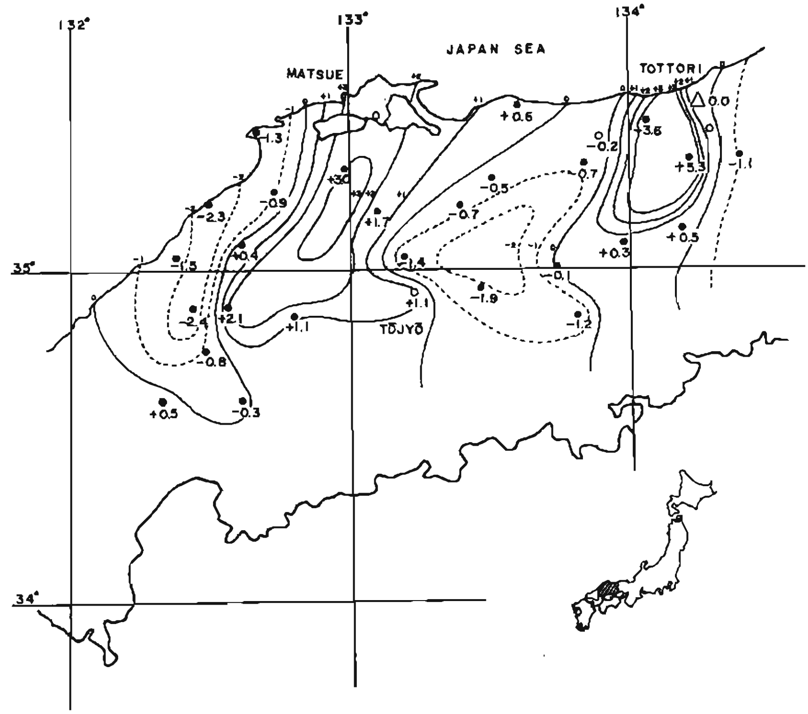

Fig. 2. The relative secular variation of the geomagnetic total intensity referring to the Tottori Micro-Earthquake Observatory, $\Delta\dot{F}(\gamma/\text{year})$, in the Chugoku district from 1965 to 1971.

- ○ the first order magnetic station
- ● the second order magnetic station
- △ the Tottori Micro-Earthquake Observatory

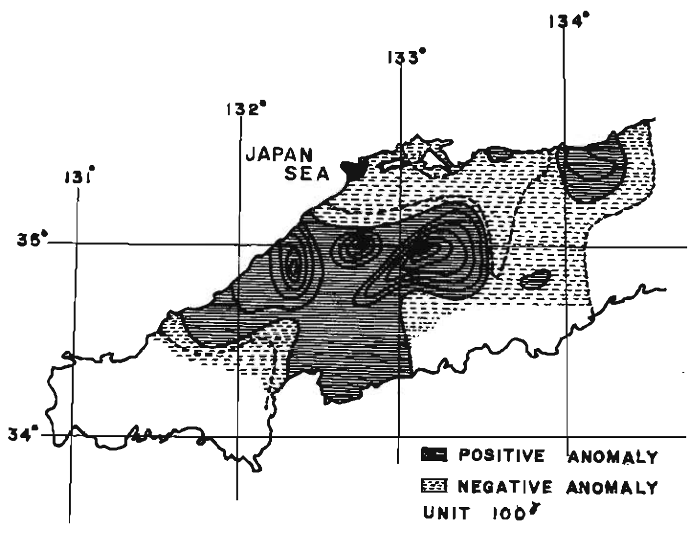

Fig. 3. Isoanomalic chart of the geomagnetic total intensity in the Chugoku district, 1960.

movements due to the horizontal compression of E–W trend in Southwest Japan.

Another feature to be noted is that the marked anomalous secular variations are recognized at the area of Hamada and its neighbours, as reported by the first order magnetic surveys repeated over a long period of time by the G.S.I.. Furthermore a fairly remarkable anomaly is found in the area of the eastern part of Tottori prefecture, where the Tottori great earthquake (magnitude of 7.3) occurred in 1943 and revealed the Yoshioka and Shikano faults. But the problem whether this anomaly truly relates to the Tottori earthquake will be left for the future.

5. Concluding Remarks

Even if an observation of the geomagnetic total intensity is made in a short interval of time such as twenty minutes with a proton precession magnetometer, it can be said that an accuracy of epoch reduction can be obtained within an accuracy of $\pm 2\sim 3\gamma$ provided that a sub-reference magnetic station is available in neighbourhood of the surveying areas. In present surveys in the Chugoku district the epoch reduction of every station has been made by using the observed values at the Tottori Micro-Earthquake Observatory. At this station, the continuous observation of the geomagnetic total intensity has been carried out since 1967, and the differences of total intensity between Tottori and the Kakioka Magnetic Observatory are well known.

Secular variation in the geomagnetic field in the Chugoku district have been estimated using the reduced values at every station obtained by the present surveys and the ones by the Geographical Survey Institute about 5 years ago. Characteristic anomalous secular variations are recognized all over the Chugoku district, of which distribution is fairly systematic. That is to say, there may exsist a marked contrast in the zone of the positive secular variation and in that of the negative. Comparing the distribution of secular variations with that of geomagnetic anomalies in the Chugoku district, some correlation between them can be seen. This leads us to the consideration that since Southwest Japan has been under the horizontal compressive stress state of E–W trend due to the neotectonic force, geomagnetic secular variations in the Chugoku district may be ascribed to the piezomagnetic effect or the crustal movements.

The especially anomalous secular variation in the neighbourhood of Yoshioka and Shikano earthquake faults is of much interest. But it can not be said immediately whether such anomalies are accidental or physically meaningful. Further repetition of the observations are going to be planned.

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