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20. *Surveys of the Geomagnetic Total Intensity in the Tokai District (1): Secular Changes during the Period from 1971 to 1978.*

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Abstract

Geomagnetic surveys have repeatedly been carried out in the Tokai District since 1971. Survey site selection has been hampered by magnetic noises due to stray currents from the electric railways. However, since 1979 twenty sites in good locations have been maintained for repeated surveys. At each site, the geomagnetic total intensity is measured every minute for 10-20 min by using the portable proton precession magnetometer which has an accuracy of 1 nT. The measured values are compared with the total intensity at the reference station, which in this case is the Yatsugatake Magnetic Observatory. Thus, secular changes of the total intensity in the Tokai area relative to the reference station can be investigated.

From 1971 to the beginning of 1979, the survey has been carried out thirteen times, although in some cases measurements were made only at some of the sites. Because of anomalies of short-period geomagnetic variations in the survey area, the difference in the total intensity between a survey site and the reference station cannot be determined very accurately. In the present survey system therefore, an anomaly of local nature, covering only a few sites, cannot be detected significantly unless the magnitude of such an anomaly is fairly large. In view of the spatial extent of an anomaly to be expected in association with a seismic event in the Tokai area, much stress has been put on the examination of an anomaly having a rather regional nature. For this purpose the survey area was divided into four survey regions and for each survey region a regional secular change was obtained by averaging secular changes observed at the survey sites in the region.

The results obtained for the period from 1971 to 1978 revealed secular changes, relative to the reference station, amounting to 1.5

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nT/yr or so at most. Such changes are characterized by a clear trend that the pattern of change in one region is very similar to that in another and the magnitude of the change tends to be large towards the south. Thus, the dependence of relative secular changes on the latitude difference between a survey region and the reference station was disclosed in the Tokai area. However, a very similar dependence was also observed for a pair of stations in the Kanto District, and it is concluded that the secular changes observed in the Tokai area are unlikely to reflect anomalies of crustal origin. Such a dependence would be merely the manifestation of spatial dependence of secular changes having their origins in the earth's core or in the magnetosphere.

1. Introduction

Changes in the geomagnetic field have sometimes been observed in association with earthquake occurrences (RIKITAKE, 1976; HONKURA, 1980). Some of them, however, have not been considered to be very significant, because the accuracy of magnetometers used for measurements of the earth's magnetic field was not very high and survey methods as well as data reduction techniques had not been carefully examined. In the meantime, the use of proton precession magnetometers of high accuracy came into fashion and recent field observations disclosed only slight changes even at the time of earthquakes greater than magnitude 6 (HONKURA et al., 1976; SHAPIRO and ABDULLABEKOV, 1978; Geomagnetic Group for Izu Peninsula, 1980).

The theory of rock magnetization changes due to stress has also advanced and enabled one to estimate geomagnetic changes to be expected on the earth's surface (e.g. NAGATA, 1969; STACEY, 1964). A more detailed theoretical examination of geomagnetic changes has been made on the basis of the dislocation theory and the result of numerical calculations was successfully applied to the changes in the total intensity observed in the Izu Peninsula (OHSHIMAN, 1980). Although much attention in the above results was put on coseismic changes, geomagnetic changes also appeared before an earthquake occurrence as clearly observed in the San Andreas fault region (SMITH and JOHNSTON, 1976).

Along the Nankai trough off the Tokai District, a seismicity-gap has been recognized (e.g. SEKIYA and TOKUNAGA, 1974). Some seismologists are afraid that this implicates an approaching earthquake. Meanwhile, ISHIBASHI (1977) pointed out that a focal area for the suspected earthquake would extend to the deep interior of the Suruga Bay. MOGI (1977) also disclosed tectonics and seismic activity in the Suruga Bay area with special attention paid to their relation with earthquakes in the Izu Peninsula.

Geomagnetic surveys have repeatedly been carried out in the Tokai area since 1971 (YUKUTAKE et al., 1974, 1976; YOSHINO et al., 1976; HONKURA et al., 1977, 1978). In view of the current discussions on the possibility of an earthquake occurrence in the Suruga Bay area, it may be high time to summarize the results obtained so far and to examine whether or not any anomalous changes in the geomagnetic field can be recognized in the Tokai area.

2. Survey system

It is certainly preferable that survey sites be established as close to an expected focal region as possible. However, site selection is hampered by two situations; an earthquake is expected to take place below the sea area where repeated surveys are by no means easy and has never been carried out so far, and noises arising through stray currents from the electric railway system, as shown by dashed lines in Fig. 1, must be avoided for precise measurements of the geomagnetic field. Under these limitations four areas were selected, as shown by Roman numerals in Fig. 1. Among them, the area IV will be the most important and the area II will also be important if an expected focal region extends to the deep interior of the Suruga Bay as claimed by ISHIBASHI (1977). In this case, the array of survey sites established along the western coast of Izu Peninsula by the Tokyo Institute of Technology (TANAKA and OHSHIMAN, 1978) and the Kakioka Magnetic Observatory (1979) is to be located at the opposite side of an expected fault line. The combination of these three areas, therefore, will provide effective information on geomagnetic changes which might be related to underground processes before and after an earthquake occurrence. The areas I and III will play rather a role as reference areas, since they are far from the expected focal region.

Measurements of the total intensity were carried out initially at 10 sites. Since then, new sites have been established from time to time and since 1979, 20 sites have been maintained. Whenever a site was found to be affected by a change in magnetic environments near the site such as the establishment of magnetic bodies, a new site was established as close to the previous one as possible. Such altered sites are indicated by station identification with a small letter a or b in Fig. 1. Capital letter G denotes the first- or second-order magnetic stations established by the Geographical Survey Institute, while E indicates survey sites established by the authors.

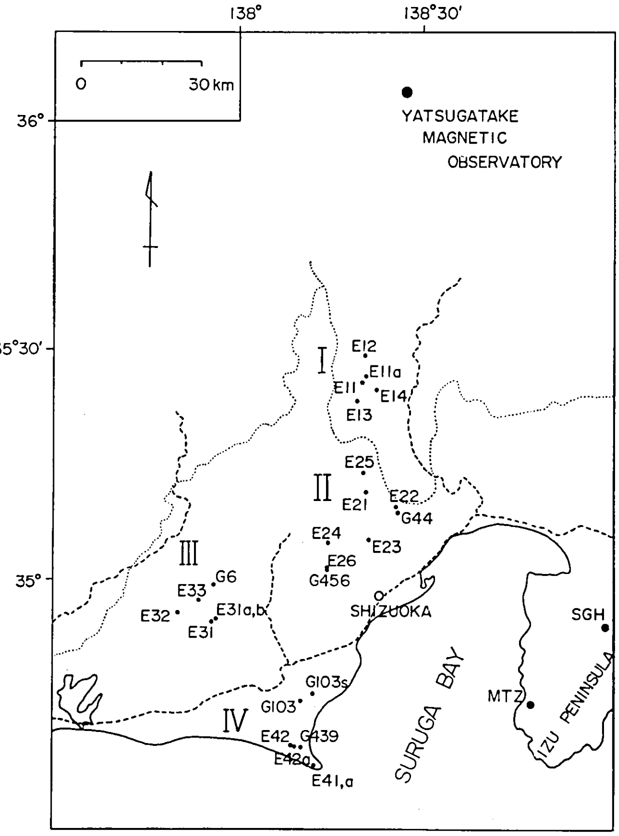

Fig. 1. Localities of survey sites in the Tokai District.
Dashed lines denote the electric railways.

The sensor position must be exactly relocated in each survey for a repeated survey to be made precisely. A criterion for site selection was considered in order to fulfill this requirement and yet maintain a simple procedure in field measurements: horizontal and vertical magnetic gradients at a site must be less than 5 nT/m. This criterion is sufficient, since relocation within a distance of 10 cm can easily be made in any situation and the accuracy of the portable proton precession magnetometer used for the present surveys is 1 nT.

Immediately before or after each survey, the calibration of the portable magnetometer was made at the Yatsugatake Magnetic Observatory which has been selected as the reference station as will be described below. The difference between values of the total intensity measured by the reference and portable magnetometers was small, within 0.3 nT or so, and comparable to the standard deviation of the mean. Therefore, such a difference has been neglected. In each survey the total intensity was measured three times every minute and the average was obtained. This procedure was repeated for 10–20 minutes at each survey site. In order to avoid a remarkable effect due to the spatially non-uniform nature of solar daily variations of the total intensity (MORI and YOSHINO, 1970), measurements were usually carried out after 16:30 (local time).

It is preferable that a reference station be located outside of a survey area and also in a tectonically non-active area. The Yatsugatake Magnetic Observatory is located about 100 km north of the present survey area and in its vicinity seismic activity is remarkably low. Therefore, this observatory has been selected as the reference station for the repeated surveys in the Tokai District. However, a serious problem arises: an effect of anomalies of short-period geomagnetic variations. It is known that the Tokai District is one of the representative anomalous regions (HONKURA, 1974) and the difference in geomagnetic total intensities at survey sites and the reference station is remarkably influenced by such an effect, particularly at the time of short-period variations of large amplitude. However, in the present survey system there is no appropriate means of overcoming such an effect except for suitable corrections applied to the observed data. More considerations about this effect will be given in the next section.

3. Differences in variations of geomagnetic total intensity between the survey area and the reference station

Continuous measurements of the geomagnetic total intensity were carried out at two sites, E11 and E41, in order to examine the effect of short-period variations. Figure 2 shows variations of total intensity observed at the survey site E41 and the reference station, and also their difference. The effect of short-period variations is so great that it seems almost impossible to obtain an accurate estimate of difference between this site and the reference station. Amplitudes of short-period variations in the total intensity difference are roughly half of those of corresponding total intensity variations at the reference station, although the relation between amplitudes seems to be somewhat complicated. A similar effect will be found at other sites belonging to the survey area IV. Therefore, the data obtained in the area IV should be carefully processed; special attention must be paid to the effect of short-period variations.

It is known that such an effect is mostly due to anomalous variations in the vertical component of the geomagnetic field. They are cor-

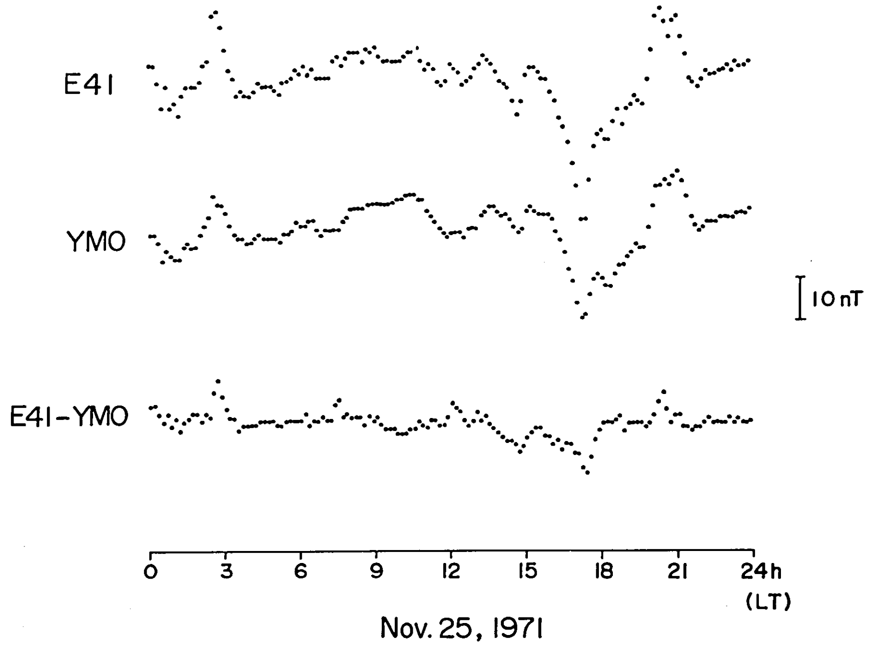

Fig. 2. Variations in the geomagnetic total intensity at the site E41 and the reference station YMO, and also total intensity differences between the two.

related with those of the horizontal components as represented by the following empirical expression:

$$\Delta Z = A\Delta H + B\Delta D$$

where ΔZ, ΔH and ΔD denote variations of the vertical, magnetically northward, and magnetically eastward components, respectively. A and B are called the transfer functions. It should be noticed that ΔD contributes to total intensity variations through ΔZ which is partly correlated with ΔD. For this reason, there is apparently a complicated relation between the total intensity difference and the total intensity at the reference station. Suitable correction would be possible if transfer functions are known at both stations.

A nature remarkably different from that found at E41 is recognized at the site E11 belonging to the survey area I as shown in Fig. 3. Although the amplitude of daily variation is somewhat larger at the reference station than E11, short-period variations during the night are similar to each other. The effect of short-period variations would also be small at other sites in the area I. Therefore, results of surveys in the area I will be fairly reliable, although corrections with the use of

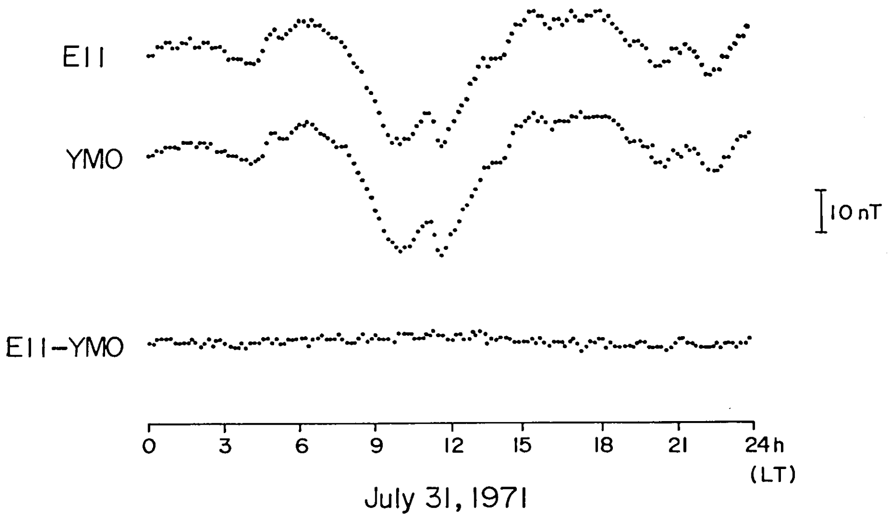

Fig. 3. Variations in the geomagnetic total intensity at the site E11 and the reference station YMO, and also total intensity differences between the two.

transfer functions might still increase the reliability.

The survey areas II and III are likely to exhibit an effect of short-period variations less remarkable than that in the area IV yet more remarkable than that in the area I. Such presumption should be verified by making continuous measurements of the total intensity in the areas II and III. In this paper, no corrections are made to the results. However, special attention will be paid to the effect of short-period variations.

4. Results of repeated surveys

During the period from 1971 to 1979, surveys of the total intensity have been carried out thirteen times, although in some cases measurements were made only at sites in the survey area IV. As mentioned in the previous section, the effect of short-period variations must be taken into account when the differences in the total intensities between survey sites and the reference station are considered. In this section, variations of the total intensity at the reference station during each survey period will be shown besides the observed results. Figures of these variations will be useful for rough estimates of possible errors due to the effect mentioned above.

In the present survey system high accuracy cannot be expected. As acceptable errors in the combination of field measurements and data reduction, two levels are set: 3 nT and 5 nT. If an error seems to be less than 3 nT, the data can be considered reliable. The data with an expected error of 3 to 5 nT will be treated as less reliable. If an error is expected to exceed 5 nT, the data would be completely unreliable.

The first survey

The means of the observed values at each site are shown in Table 1-1 together with the corresponding means at the reference station and the differences between respective pairs of means. Figure 4-1 shows variations of total intensity at the reference station. The time when measurements were made is shown by a bar for each site. As mentioned in the previous section, the sites belonging to the survey area I are unlikely to be affected greatly by short-period variations except during severe magnetic storms. Measurements at G456 happened to be made at a magnetically quiet time. Therefore, all the data seem to be reliable in the sense that they are not contaminated by the effect of short-period variations.

Table 1-1. Results of the first survey (1971).

Site	Date	Time	$\bar{F}$	$\bar{F}_{ref}$	$\Delta\bar{F}$
G456	Aug. 1	17 : 06—17 : 15	45,871.2nT	46,153.6nT	−282.4nT
E11	1	23 : 00—23 : 59	46,017.7	46,160.6	−142.9
E12	Jul. 30	19 : 25—19 : 34	46,159.4	46,155.0	4.4
E13	30	18 : 20—18 : 29	45,993.5	46,155.9	−162.4

The second survey

The results of the second survey are shown in Table 1-2. As shown in Fig. 4-2, measurements at G6, E31, and E21 happened to be made at the time of high disturbance. However, the amplitudes of short-period (shorter than a few hours) variations superposed on rather long-period ones seem to be small. It is known that the anomaly in geomagnetic variations is reduced to a considerable extent as their period becomes

Table 1-2. Results of the second survey (1971).

Site	Date	Time	$\bar{F}$	$\bar{F}_{ref}$	$\Delta\bar{F}$
G6	Nov. 25	16 : 40—17 : 00	45,855.2nT	46,117.6nT	−262.4*nT
G44	27	16 : 19—16 : 50	45,891.2	46,142.8	−251.6
G439	27	19 : 12—19 : 23	45,616.2	46,138.8	−522.6
E21	26	18 : 01—18 : 10	45,834.6	46,117.8	−283.2*
E31	25	18 : 31—18 : 40	45,802.9	46,087.6	−284.7*
E42	27	19 : 58—20 : 07	45,635.7	46,134.7	−499.0

* unreliable.

long (HONKURA, 1974). Therefore, errors arising from the effect due to the anomaly are unlikely to exceed 5 nT, although the effect of long-period variations in the total intensity must be investigated in detail through continuous measurements in the survey area. The error level of the data at E42 is expected to be about 5 nT, and the data will be unreliable. Errors at G44 and G439 would be less than 3 nT and, therefore, the data at these sites can be considered as being reliable.

The third survey

The results of the third survey are shown in Table 1-3. In this case, the effect of short-period variations would be rather small except for the site G456 where an extremely large variation amounting to 30 nT or so in amplitude will cause a large error exceeding 5 nT. The data at G456 should not be included in the analysis of a secular variation at this site. The data at G44 and E21 seem to be contaminated by long-period variations, but errors will not exceed 5 nT. The data at other sites can be considered to be reliable.

Table 1-3. Results of the third survey (1972).

Site	Date	Time	$\bar{F}$	$\bar{F}_{ref}$	$\Delta\bar{F}$
G6	Oct. 17	16 : 42—16 : 51	45,875.6nT	46,136.0nT	−260.4nT
G44	18	16 : 31—16 : 45	45,881.0	46,131.5	−250.5*
G439	16	17 : 15—17 : 24	45,602.1	46,124.8	−522.7
G456	14	18 : 15—18 : 24	45,799.3	46,093.7	−294.4**
E11	15	19 : 16—19 : 25	45,992.9	46,131.6	−138.7
E12	15	18 : 35—18 : 44	46,136.3	46,131.7	4.6
E13	15	17 : 15—17 : 24	45,965.5	46,128.4	−162.9
E21	18	22 : 16—22 : 25	45,842.3	46,122.9	−280.6*
E31	18	9 : 20— 9 : 29	45,846.8	46,128.1	−281.3*
E41	16	18 : 20—18 : 29	45,582.6	46,126.8	−544.2
E42	16	17 : 47—17 : 56	45,626.5	46,123.5	−497.0

* unreliable, ** completely unreliable.

The fourth survey

The results of the fourth survey are shown in Table 1-4. Fortunately the survey was carried out under fairly good conditions. Slight errors might be expected at sites belonging to the area IV and also at E31. All the data given in Table 1-4 can be treated as reliable ones.

The fifth survey

The results of the fifth survey are shown in Table 1-5. Measurements were made under relatively good conditions. G103s and G103 might be somewhat affected by long-period variations, although errors

Table 1-4. Results of the fourth survey (1973).

Site	Date	Time	$\bar{F}$	$\bar{F}_{ref}$	$\Delta\bar{F}$
G6	Nov. 11	16 : 35—16 : 46	45,876.3nT	46,133.4nT	−257.1nT
G44	13	16 : 30—16 : 41	45,884.9	46,133.3	−248.4
G439	10	17 : 36—17 : 45	45,609.5	46,126.2	−516.7
G456	12	16 : 39—16 : 50	45,855.9	46,132.7	−276.8
E11	14	18 : 40—18 : 49	45,986.2	46,128.3	−142.1
E12	14	17 : 58—18 : 08	46,132.4	46,126.6	5.8
E13	14	16 : 45—16 : 56	45,967.3	46,127.2	−159.9
E21	12	18 : 36—18 : 45	45,851.7	46,132.2	−280.5
E31	11	17 : 32—17 : 41	45,847.5	46,126.8	−279.3
E41	10	18 : 07—18 : 17	45,590.0	46,125.6	−535.6
E42	10	17 : 00—17 : 14	45,639.3	46,128.9	−489.6

Table 1-5. Results of the fifth survey (1974).

Site	Date	Time	$\bar{F}$	$\bar{F}_{ref}$	$\Delta\bar{F}$
G6	Dec. 5	16 : 30—16 : 40	45,876.4nT	46,134.4nT	−258.0nT
G44	4	20 : 32—20 : 42	45,881.1	46,128.6	−247.5
G103	7	22 : 29—22 : 39	45,666.6	46,122.0	−455.4*
G103s	6	16 : 00—16 : 10	45,703.2	46,139.1	−435.9*
G439	6	17 : 33—17 : 42	45,612.1	46,131.5	−519.4
G456	4	18 : 34—18 : 43	45,847.8	46,130.1	−282.3
E11	3	18 : 21—18 : 30	45,988.1	46,129.3	−141.2
E12	3	17 : 47—17 : 57	46,138.4	46,131.3	7.1
E13	3	16 : 45—16 : 54	45,971.6	46,133.2	−161.6
E21	4	16 : 45—16 : 54	45,849.5	46,130.1	−280.6
E41	6	18 : 00—18 : 10	45,597.1	46,129.7	−532.6
E42	6	17 : 08—17 : 18	45,638.1	46,132.7	−494.6

* unreliable.

are unlikely to be very large. The other data are fairly reliable. All the data including those at G103s and G103 will be used for analysis of secular changes.

The sixth survey

The results of the sixth survey are shown in Table 1-6. Short-period variations frequently appeared as shown in Fig. 4-6. However, most of their amplitudes are small and errors are expected to be less than 3 nT, even at sites in area IV. E21 might be slightly affected by a long-period variation. All the data of this survey can be considered to be reliable.

The seventh survey

The results of the seventh survey are shown in Table 1-7. Unfortu-

Table 1-6. Results of the sixth survey (1975).

Site	Date	Time	$\bar{F}$	$\bar{F}_{ref}$	$\Delta\bar{F}$
G6	Nov. 11	16 : 56—17 : 10	45,870.6nT	46,128.6nT	−258.0nT
G44	10	17 : 31—17 : 42	45,871.0	46,118.5	−247.5
G103	12	22 : 35—22 : 49	45,677.1	46,132.0	−454.9
G103s	12	23 : 43—23 : 52	45,693.6	46,130.0	−436.4
G439	12	20 : 41—20 : 50	45,611.9	46,130.1	−518.2
G456	13	1 : 55— 2 : 04	45,851.5	46,132.0	−280.5
E11a	13	18 : 01—18 : 10	45,970.2	46,134.3	−164.1
E12	13	18 : 33—18 : 42	46,140.5	46,135.1	5.4
E13	13	17 : 11—17 : 20	45,974.9	46,135.7	−160.8
E21	13	7 : 39— 7 : 48	45,859.0	46,139.8	−280.8
E22	10	16 : 56—17 : 05	46,065.0	46,121.8	−56.8
E31a	11	18 : 37—18 : 46	45,836.5	46,127.9	−291.4
E41	12	21 : 19—21 : 28	45,599.2	46,128.2	−529.0

Table 1-7. Results of the seventh survey (1976).

Site	Date	Time	$\bar{F}$	$\bar{F}_{ref}$	$\Delta\bar{F}$
G6	Nov. 20	17 : 59—18 : 13	45,890.0nT	—	−255.1nT
G44	21	23 : 24—23 : 38	45,900.9	—	−245.3
G103	19	18 : 01—18 : 20	45,694.2	—	−450.3
G103s	19	18 : 45—18 : 59	45,714.7	—	−432.5
G439	19	20 : 00—20 : 09	45,635.3	—	−514.8
G456	21	20 : 10—20 : 19	45,865.2	—	−281.6
E11a	22	3 : 05— 3 : 14	45,982.6	—	−162.4
E12	22	3 : 44— 3 : 53	46,155.3	—	7.3
E13	22	2 : 10— 2 : 19	45,996.2	—	−153.6
E21	21	16 : 55—17 : 04	45,870.9	—	−277.3
E22	21	22 : 52—23 : 01	46,097.0	—	−50.6
E23	21	17 : 46—17 : 55	45,858.2	—	−289.9
E24	21	19 : 21—19 : 30	45,904.2	—	−241.7
E31a	20	17 : 11—17 : 20	45,860.2	—	−287.9
E32	20	18 : 54—19 : 03	45,923.7	—	−219.3
E41	19	20 : 28—20 : 37	45,625.8	—	−523.6

nately the data at the reference station, the Yatsugatake Magnetic Observatory, were not available for the survey period because of failure in the recording system. The observed data at each survey site, therefore, were compared to the corresponding data at the Kakioka Magnetic Observatory. The difference of the total intensities between the reference station and the Kakioka Observatory was determined from a large amount of night time values immediately before and after the seventh survey. Using the difference thus determined, $\Delta\bar{F}$ was obtained for each site as shown in Table 1-7.

Figure 4-7 shows variations of total intensity at the Kakioka Magnetic Observatory. It is known that transfer functions A and B at the Kakioka Observatory are very similar to those at the survey area IV (RIKITAKE and HONKURA, 1973). Therefore, the amplitude of short-period variation tends to be larger at the Kakioka Observatory than at the reference station. It is concluded from Fig. 4-7 that all the data of the seventh survey are reliable.

The eighth and ninth surveys

In view of the importance of the area IV, surveys were repeated in this area more frequently than in the other areas. The results of the eighth and ninth surveys are shown in Tables 1-8 and 1-9, respectively. As can be seen in Figs. 4-8 and 4-9, the effect of short-period variations seems to be fairly small and all the data are reliable.

Table 1-8. Results of the eighth survey (1977).

Site	Date	Time	$\bar{F}$	$\bar{F}_{ref}$	$\Delta\bar{F}$
G103	Apr. 13	19 : 49—20 : 08	45,696.5nT	46,149.3nT	−452.8nT
G103s	13	20 : 34—20 : 48	45,715.8	46,150.1	−434.3
G439	13	21 : 18—21 : 27	45,633.0	46,150.2	−517.2
E41	13	19 : 05—19 : 14	45,618.0	46,148.7	−530.7
E42a	13	17 : 47—17 : 58	45,616.5	46,146.4	−529.9

Table 1-9. Results of the ninth survey (1977).

Site	Date	Time	$\bar{F}$	$\bar{F}_{ref}$	$\Delta\bar{F}$
G439	Sep. 5	18: 27—18: 36	45,642.9nT	46,161.8nT	−518.9nT
E41	5	18: 53—19: 02	45,631.6	46,161.6	−530.0
E42a	5	18: 06—18: 15	45,631.6	46,162.6	−531.0

The tenth survey

The results of the tenth survey are shown in Table 1-10. All the data except for those at E22 and G44 were obtained during a relatively quiet time and, therefore, would be reliable. E21 and E23 might be affected to some extent by long-period variations. Errors due to this effect at E22 and G44, however, are unlikely to exceed 5 nT and the data at these sites will be used for analysis of secular changes.

The eleventh survey

In view of a possible relation between tectonic activities in the Izu Peninsula and the Tokai District (e. g. MOGI, 1977), the survey was carried out in the Tokai District two months after the occurrence of the Izu-

Table 1-10. Results of the tenth survey (1977).

Site	Date	Time	$\bar{F}$	$\bar{F}_{ref}$	$\Delta\bar{F}$
G6	Nov. 28	17: 49—18: 03	45,897.8nT	46,154.0nT	−256.2nT
G44	30	17: 47—18: 01	45,910.3	46,157.4	−247.1*
G103	29	17: 34—17: 53	45,703.3	46,157.4	−454.1
G103s	29	17: 00—17: 14	45,723.1	46,158.2	−435.1
G439	29	18: 25—18: 34	45,638.8	46,156.3	−517.5
G456	27	18: 26—18: 35	45,864.1	46,147.3	−283.2
E11a	25	18: 16—18: 25	45,995.6	46,158.1	−162.5
E12	25	18: 44—18: 53	46,164.7	46,159.7	5.0
E13	25	17: 14—17: 23	46,008.2	46,163.3	−155.1
E14	25	17: 46—17: 55	45,936.5	46,159.7	−223.2
E21	26	17: 10—17: 19	45,841.5	46,125.8	−284.3
E22	30	17: 15—17: 27	46,106.1	46,159.1	−53.0*
E23	26	17: 59—18: 08	45,836.2	46,127.7	−291.5
E24	27	17: 41—17: 50	45,904.9	46,148.8	−243.9
E31a	28	17: 07—17: 16	45,865.0	46,156.0	−291.0
E32	28	19: 03—19: 12	45,939.3	46,158.4	−219.1
E33	28	18: 27—18: 36	45,900.4	46,155.5	−255.1
E41	29	19: 10—19: 19	45,625.4	46,157.1	−531.7
E41a	29	19: 23—19: 32	45,616.1	46,157.1	−541.0
E42a	29	18: 47—18: 56	45,625.5	46,155.5	−530.0

* unreliable.

Table 1-11. Results of the eleventh survey (1978).

Site	Date	Time	$\bar{F}$	$\bar{F}_{ref}$	$\Delta\bar{F}$
G6	Mar. 23	17 : 31—17 : 50	45,897.0nT	46,154.1nT	−257.1nT
G44	25	17 : 15—17 : 34	45,917.3	46,165.4	−248.1
G103	24	17 : 24—17 : 43	45,705.8	46,161.1	−455.3
G103s	24	16 : 49—17 : 03	45,723.4	46,162.7	−439.3
G439	24	18 : 10—18 : 24	45,643.9	46,161.1	−517.2
G456	21	17 : 51—18 : 00	45,867.1	46,150.9	−283.8
E11a	20	18 : 07—18 : 21	45,992.0	46,154.4	−162.4
E12	20	18 : 40—18 : 51	46,165.9	46,158.7	7.2
E13	20	16 : 45—16 : 59	46,002.8	46,158.4	−155.6
E14	20	17 : 27—17 : 41	45,929.9	46,154.1	−224.2
E21	22	17 : 36—17 : 50	45,879.7	46,162.1	−282.4
E22	25	16 : 46—17 : 00	46,115.7	46,170.6	−54.9
E23	22	16 : 47—17 : 01	45,875.4	46,167.8	−292.4
E24	21	16 : 46—17 : 00	45,911.3	46,156.6	−245.3
E25	22	18 : 08—18 : 22	45,880.7	46,157.6	−276.9
E31a	23	16 : 45—16 : 59	45,862.2	46,155.0	−292.8
E32	23	18 : 54—19 : 08	45,936.3	46,155.7	−219.4
E33	23	18 : 14—18 : 28	45,902.7	46,155.3	−252.6
E41a	24	19 : 05—19 : 19	45,624.4	46,165.9	−541.5
E42a	24	18 : 36—18 : 50	45,634.3	46,165.0	−530.7

Oshima-Kinkai earthquake of magnitude 7.0 in the eastern part of the Peninsula.

The results of the eleventh survey are shown in Table 1-11. As shown in Fig. 4-11, the amplitudes of short-period variations are relatively small when measurements at each station were made. However, some sites seem to be affected by long-period variations, although errors due to them would not exceed 3 nT. All the data shown in Table 1-11, therefore, can be considered to be reliable.

The twelfth survey

The twelfth survey was carried out near the end of the year as usual. Its results are shown in Table 1-12. During the survey period, no remarkable variations of short period appeared as recognized in Fig. 4-12. Sites belonging to the survey area IV might somewhat be affected by long period variations. However, errors due to them are unlikely to exceed 3 nT and all the data of the twelfth survey seem to be reliable. The results of the eleventh and twelfth surveys will provide some information on whether or not any anomalies in the geomagnetic field appeared in the Tokai area in association with the Izu-Oshima-Kinkai

Table 1-12. Results of the twelfth survey (1978).

Site	Date	Time	$\bar{F}$	$\bar{F}_{ref}$	$\Delta\bar{F}$
G6	Dec. 11	17 : 31—17 : 50	45,922.6nT	46,177.3nT	−254.7nT
G44	13	18 : 07—18 : 26	45,920.3	46,166.4	−246.1
G103	12	17 : 19—17 : 38	45,732.5	46,182.6	−450.1
G103s	12	16 : 38—17 : 00	45,751.4	46,185.0	−433.6
G439	12	18 : 10—18 : 24	45,666.3	46,179.7	−513.4
G456	10	17 : 34—17 : 43	45,894.9	46,175.6	−280.7
E11a	9	17 : 54—18 : 08	46,010.1	46,171.8	−161.7
E12	9	18 : 27—18 : 41	46,178.9	46,171.5	7.4
E13	9	16 : 36—16 : 50	46,033.7	46,175.5	−141.8
E14	9	17 : 17—17 : 31	45,953.6	46,173.5	−219.9
E21	10	20 : 16—20 : 25	45,893.7	46,174.4	−280.7
E22	13	17 : 45—17 : 54	46,114.2	46,166.7	−52.5
E23	10	19 : 33—19 : 42	45,884.3	46,173.9	−289.6
E24	10	16 : 53—17 : 02	45,933.8	46,177.4	−243.6
E25	10	20 : 47—20 : 56	45,898.6	46,174.6	−276.0
E26	10	17 : 46—17 : 55	45,888.0	46,174.9	−286.9
E31b	11	16 : 44—16 : 53	45,893.6	46,177.7	−284.1
E32	11	18 : 49—19 : 03	45,962.3	46,178.2	−215.9
E33	11	18 : 13—18 : 22	45,926.1	46,177.7	−251.6
E41a	12	19 : 08—19 : 22	45,637.0	46,179.4	−542.4
E42a	12	18 : 37—18 : 51	45,656.2	46,177.1	−520.9

earthquake.

The thirteenth survey

Measurements of the total intensity in the survey area IV were again carried out in March, 1979. The results of this survey are shown

Table 1-13. Results of the thirteenth survey (1979).

Site	Date	Time	$\bar{F}$	$\bar{F}_{ref}$	$\Delta\bar{F}$
G103	Mar. 18	17 : 46—18 : 05	45, 714. 2nT	46, 167. 4nT	−453. 2nT
G103s	18	17 : 14—17 : 28	45, 733. 3	46, 170. 1	−436. 8
G439	18	18 : 34—18 : 48	45, 651. 5	46, 168. 1	−516. 6
E41a	18	20 : 25—20 : 39	45, 629. 4	46, 172. 3	−542. 9
E42a	18	19 : 58—20 : 12	45, 646. 3	46, 171. 8	−525. 5

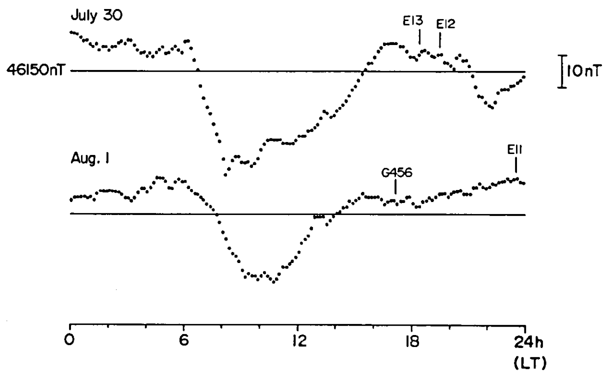

Fig. 4-1.

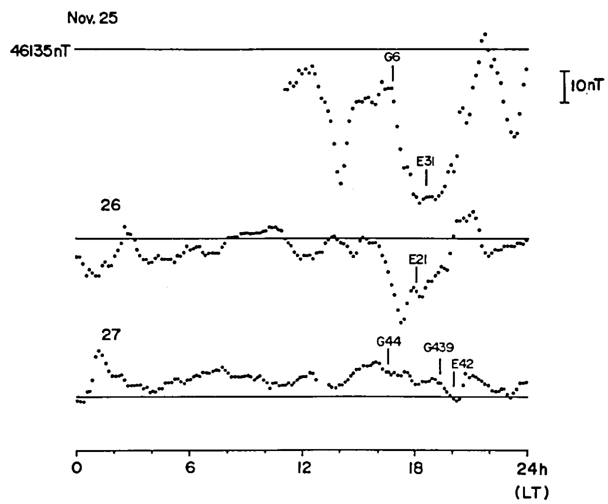

Fig. 4-2.

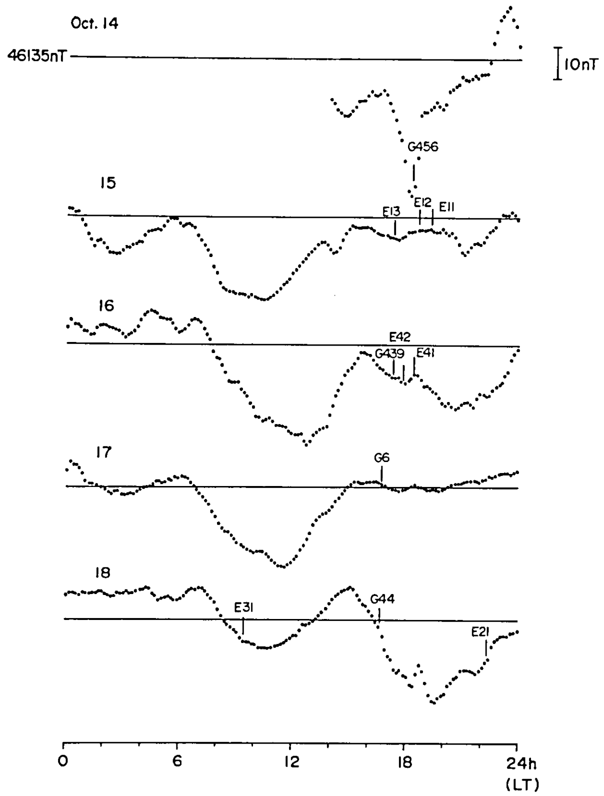
Oct. 14
46135nT
10nT
G456
15
E13
E12
E11
16
E42
G439
E41
17
G6
18
E31
G44
E21
0
6
12
18
24h
(LT)

Fig. 4-3.

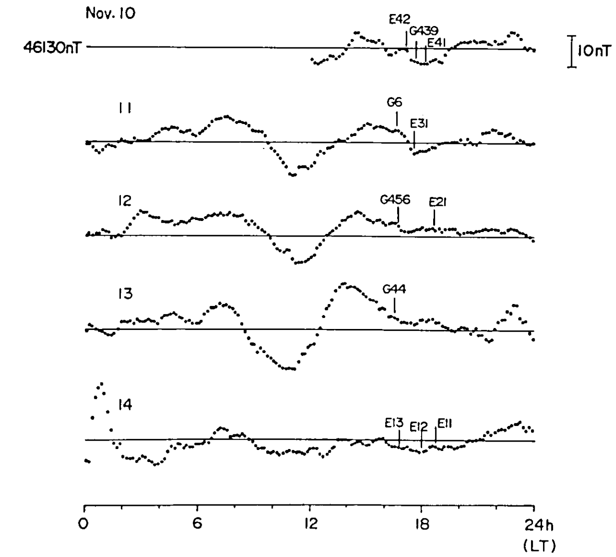
Nov. 10
46130nT
E42
G439
E41
10nT
11
G6
E31
12
G456
E21
13
G44
14
E13
E12
E11
0
6
12
18
24h
(LT)

Fig. 4-4.

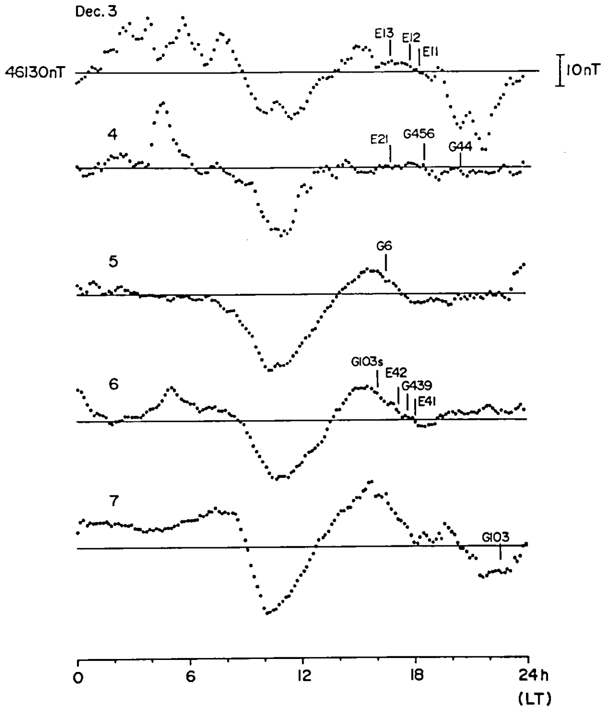
Dec. 3
46130nT
10nT
E13
E12
E11
4
E21
G456
G44
5
G6
6
G103s
E42
G439
E41
7
G103
0
6
12
18
24h
(LT)

Fig. 4-5.

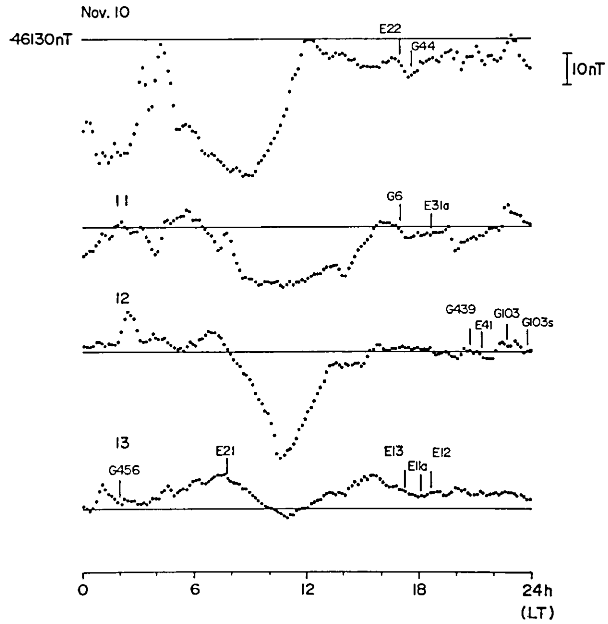
Nov. 10
46130nT
10nT
E22
G44
11
G6
E31a
12
G439
E41
G103
G103s
13
G456
E21
E13
E11a
E12
0
6
12
18
24h
(LT)

Fig. 4-6.

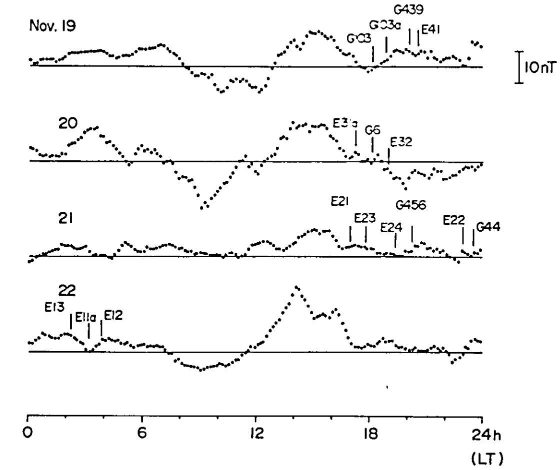

Fig. 4-7.

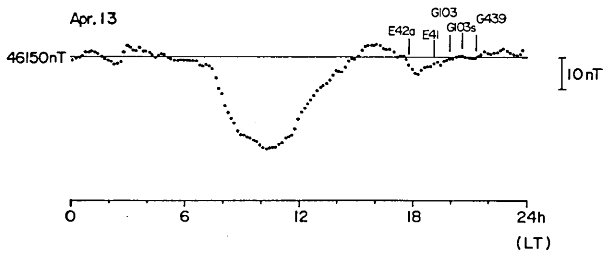

Fig. 4-8.

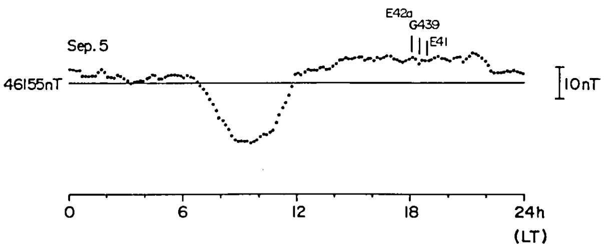

Fig. 4-9.

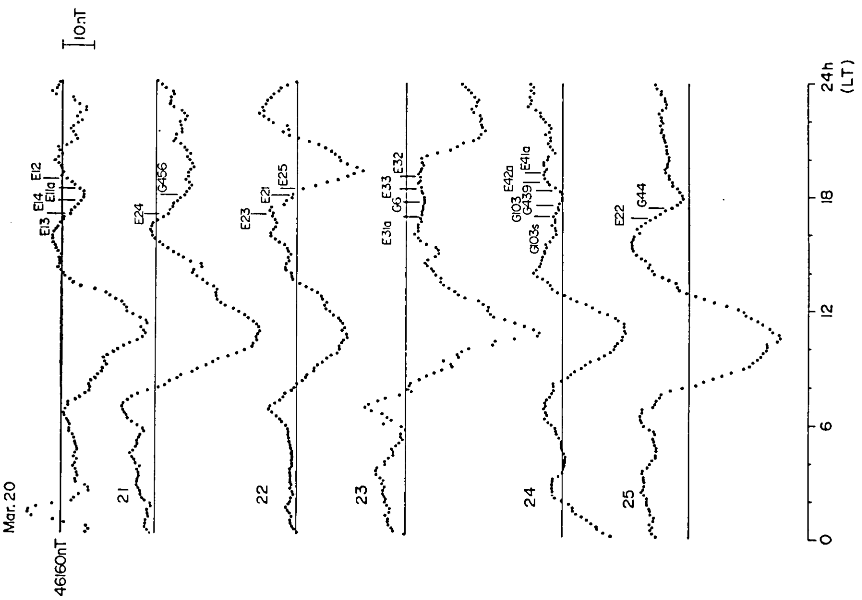

Fig. 4-11.

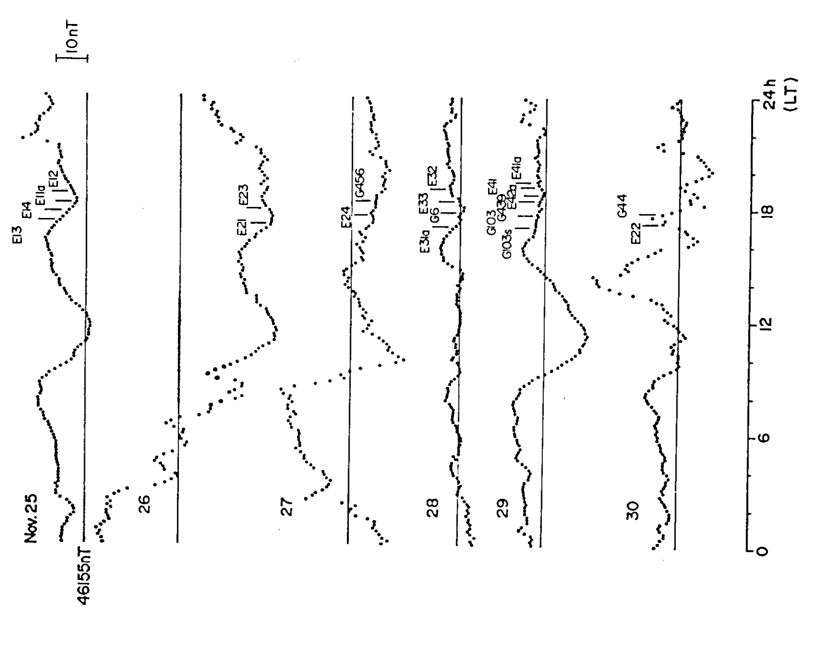

Fig. 4-10.

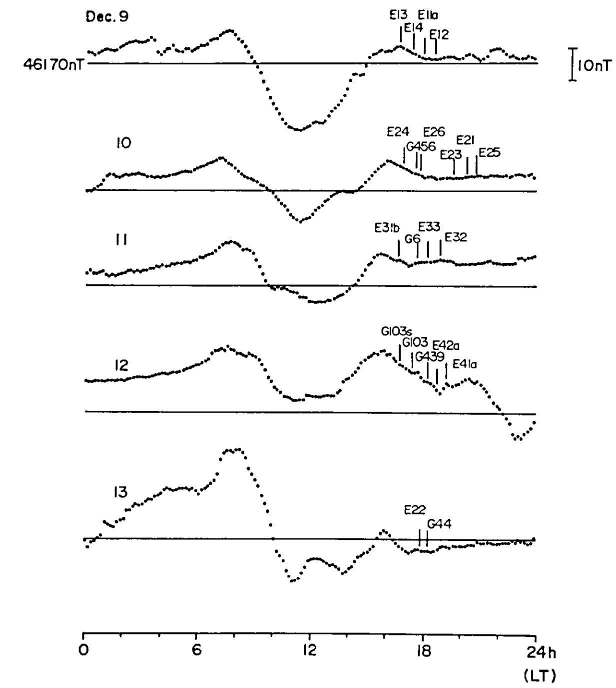

Fig. 4-12.

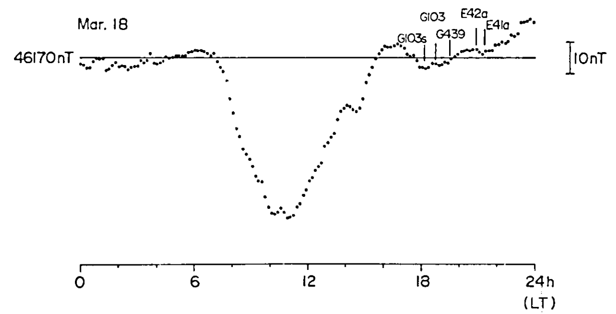

Fig. 4-13.

Fig. 4. Variations in the total intensity at the reference station during the respective surveys. The time of measurement is shown by a bar for each survey site.

in Table 1-13. Figure 4-13 shows a large amplitude of the solar daily variation and yet small amplitudes of short-period variations during measurements at each site. All the data would be significant at the error level of 3 nT.

5. Secular changes at survey sites relative to the reference station

The results of the repeated surveys disclose secular changes of total intensity at each site relative to the reference station. Figure 5-1 shows secular changes at each site in the survey area I. Although slight fluctuations exist, no remarkable change was observed in this area. The site E12 has been well maintained and provides useful information. Secular changes in the area II are shown in Fig. 5-2. The result of the third survey (1972) at G456 is not shown in this figure since it was remarkably contaminated by the effect of short-period variations. E21, G456, and G44 provide important information on secular changes in this area. Fluctuations tend to become larger compared to the result shown in Fig. 5-1, which seems to have resulted from more contamination due to the enhanced effect of short-period variations. The secular change at G44 shows the trend of increase. However, the change is much smaller than 2 nT/yr and, therefore, it cannot be considered to be anomalous if the criterion which TAZIMA (1968) set for the relation between secular changes and tectonic activities still holds in the present area.

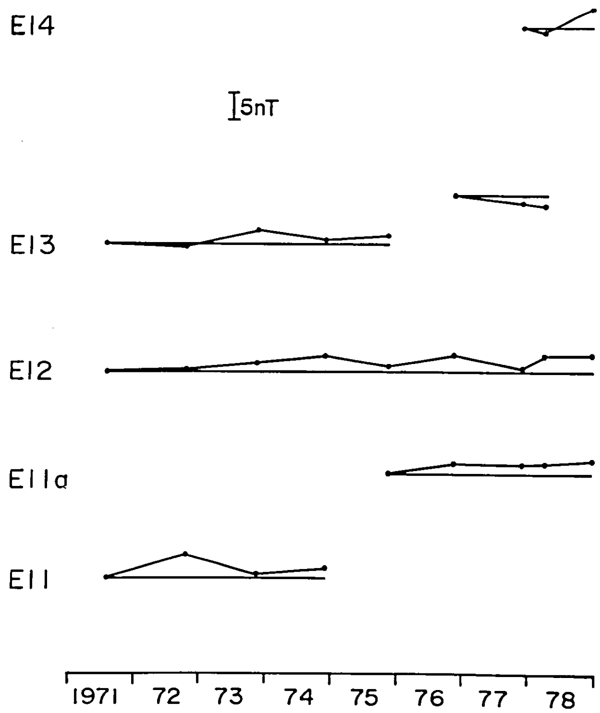

Fig. 5-1.

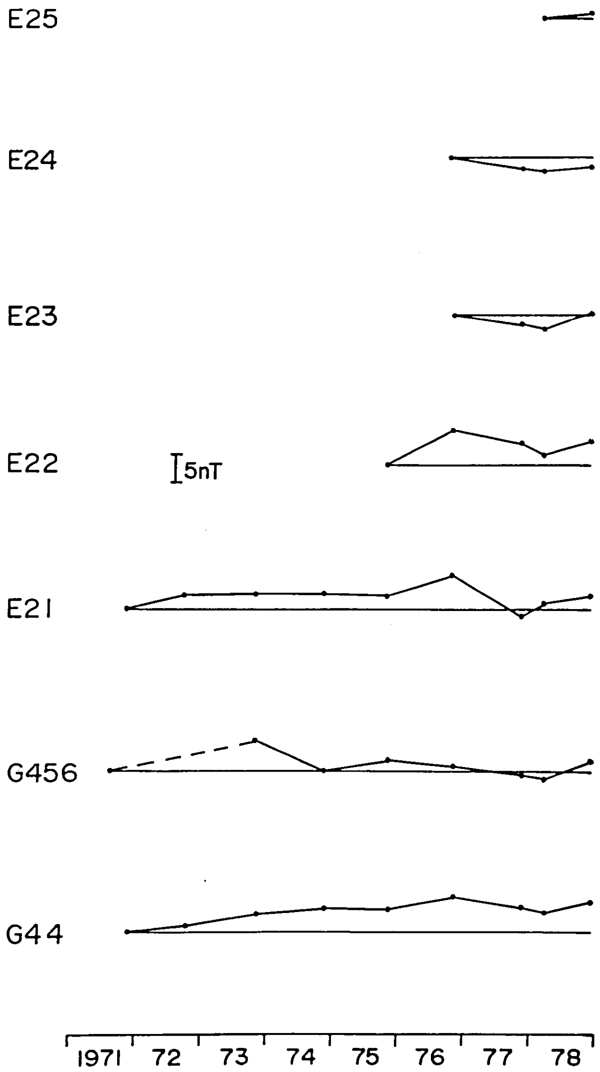

Fig. 5-2.

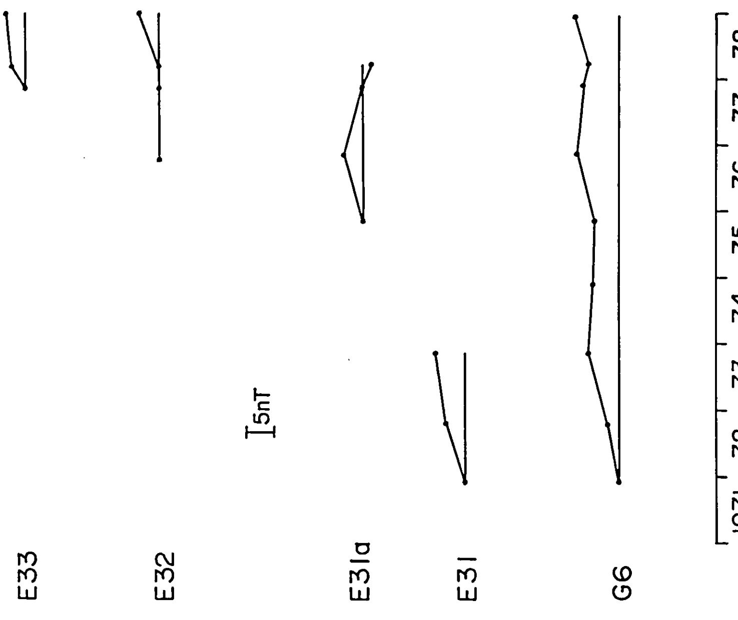

Fig. 5-3.

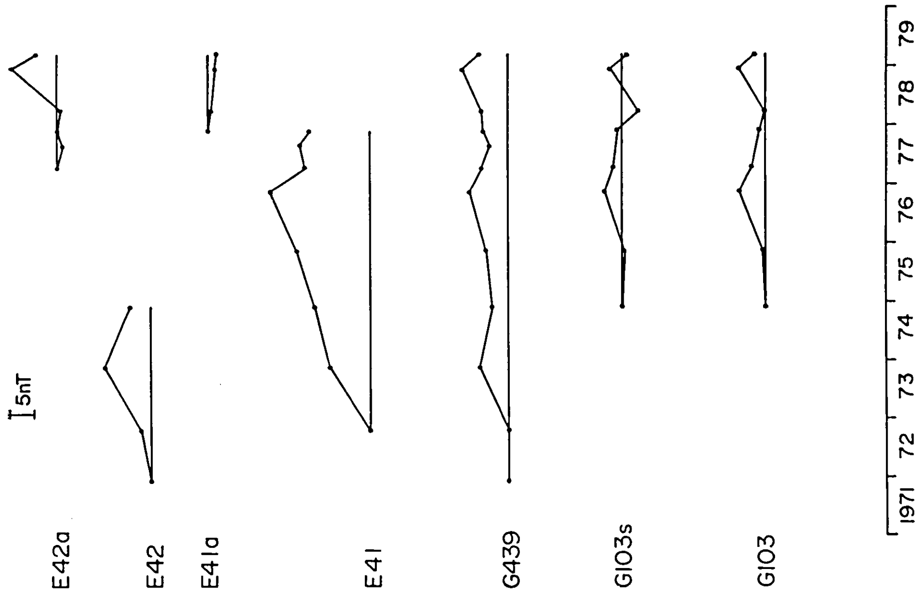

Fig. 5-4.

Fig. 5. Secular changes of total intensity at respective survey sites relative to the reference station.

The secular change at G6 in the survey area III is very similar to the one at G44, as can be seen in Fig. 5-3. The amount of change is slightly larger at G6 but still below the level of 2 nT/yr. A similar trend is also found at G439 in the survey area IV as is shown in Fig. 5-4.

The secular change observed at E41 is remarkable and it exceeded 2 nT/yr during the period from 1972 to 1976, although the pattern of change turned to decrease after 1976. However, this site might have been affected by an artificial change in magnetic environments during 1973 to 1974, because the nearby school building was being rebuilt. Unfortunately, a detailed examination of this possibility was not made at that time and nothing is clear at present about how great the site was magnetically affected. If the change between 1973 and 1974 is contaminated by such an artificial alteration and the actual change follows a pattern similar to that observed at E42 and G439, the secular change at E41 seems to be in good agreement with the other sites in the area IV. In this sense, the secular change observed at E41 cannot be concluded as anomalous. Moreover, the area IV is greatly influenced by short-period variations and, therefore, under the present survey system a detailed discussion would be meaningless unless appropriate corrections are made to the observed data.

Figures 6-1 to 6-7 show the spatial distributions of secular variations during respective periods shown in the figures. As found from Fig. 6-6, no remarkable changes were observed in the Tokai area in

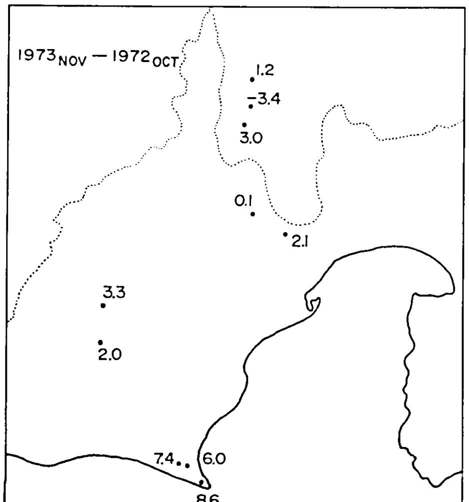

Fig. 6-1.

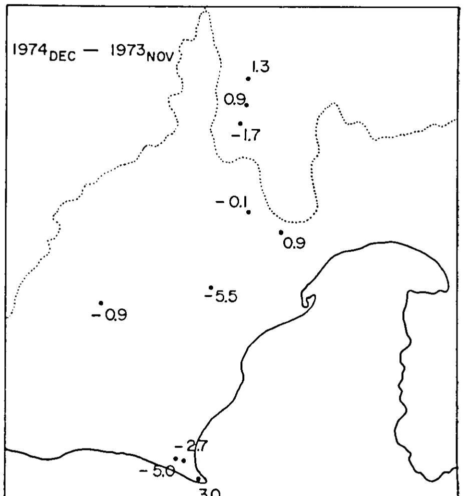

Fig. 6-2.

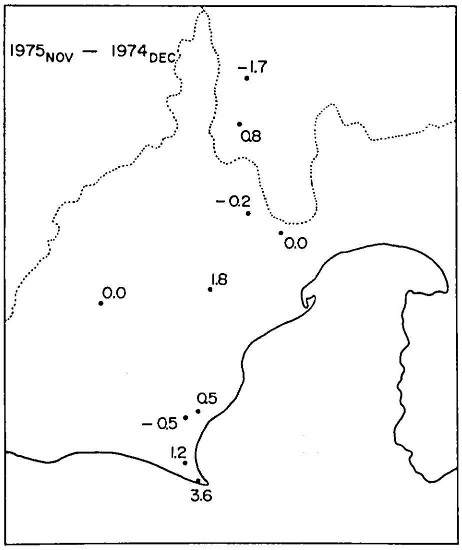

Fig. 6-3.

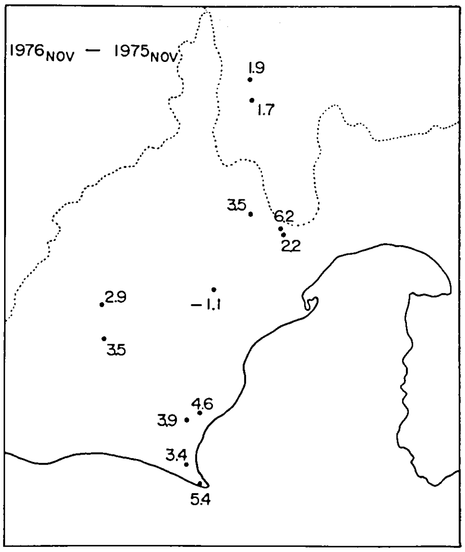

Fig. 6-4.

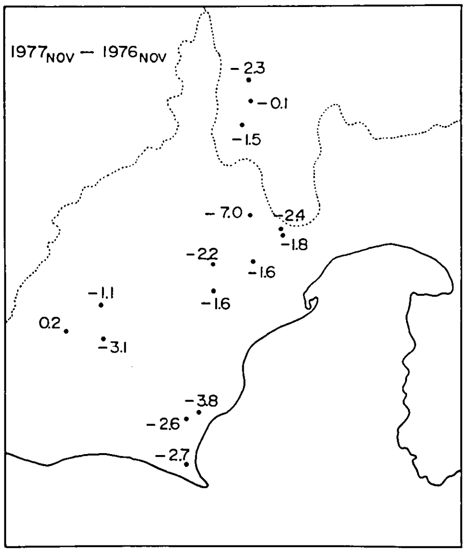

Fig. 6-5.

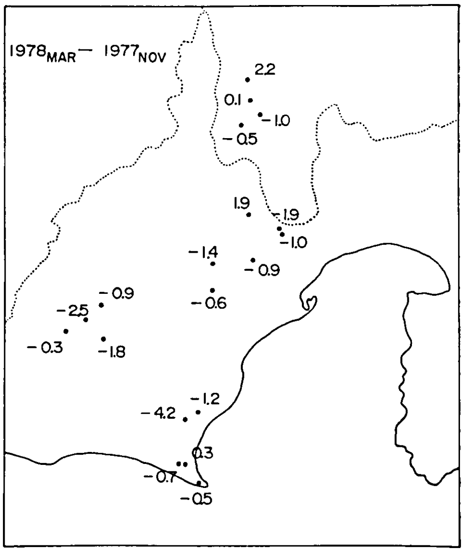

Fig. 6-6.

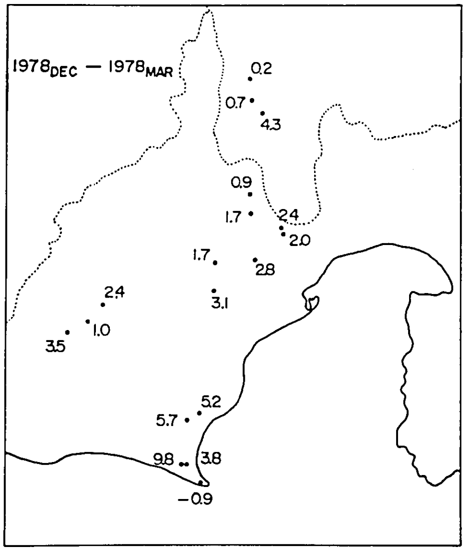

Fig. 6-7.

Fig. 6. Spatial dependence of secular changes of total intensity for respective periods shown in the figures.

association with the Izu-Oshima-Kinkai earthquake of 1978. It seems interesting to point out that a general pattern can be recognized, although fluctuations probably due to the effect of short-period variations obscure such a pattern in some cases. The tendency of increase or decrease prevails over the whole survey area and the magnitude of change tends to increase towards the south. This general pattern can be classified into three types; an overall increase (I), virtually no change (II), and an overall decrease (III). Figures 6-1, 6-4, and 6-7 fall under type I and Fig. 6-3 will be characterized by type II. The others correspond to type III.

Two possibilities can be considered for each secular change. One is that the observed secular changes are the results of changes in magnetization of crustal rock presumably due to a change in stress state. If this is the case, the anomalous area should be located south of the present survy area, as can be inferred from the spatial dependence of the observed secular variations. Then, the present results are very important from the viewpoint of earthquake prediction. The other possibility, which is more likely as will be discussed in the next section, is that the secular changes are merely the manifestation of total intensity variations having origins outside the earth or in the earth's core. If this is the case, the observed secular changes have nothing to do with crustal phenomena.

6. Spatial dependence of secular changes averaged in the respective survey areas

In the previous section, a spatial dependence of secular changes was found in spite of some fluctuations. In order to disclose such a dependence more clearly, a regional secular change will be examined for each survey area on the basis of the averages of changes observed at survey sites belonging to the respective area during the two consecutive surveys. Fig. 7 shows the secular changes (relative to the reference station) thus obtained for each survey area. Since the effect of short-period variations is likely to be rather random, fluctuations due to the effect are reduced in the average procedure. A systematic pattern can then be obtained as clearly shown in Fig. 7. The magnitude of secular change tends to be large towards the south from the reference station as noted in the previous section.

One of the means of discriminating a secular change of crustal origin is the comparison between spatial dependences of secular changes, in the present case in the north-south direction, in two regions under similar

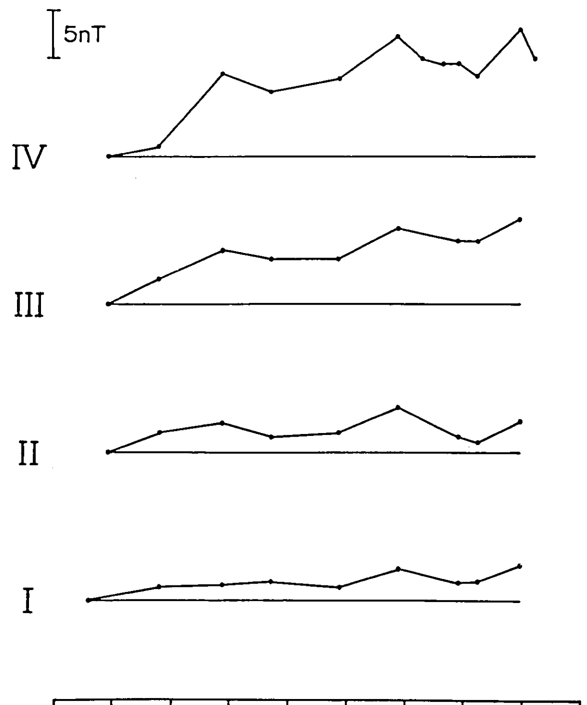

Fig. 7. Secular changes of total intensity averaged within each survey area.

situation. Fortunately, two observatories are available for this purpose: the Kakioka Magnetic Observatory and the Kanozan Geodetic Observatory. These two observatories are about 110 km apart from each other in an approximately north-south direction. Coincidentally, the distance between these two observatories is very similar to that for the pair of the Tokai area and the Yatsugatake Observatory.

Figure 8 shows secular changes of the total intensity at the Yatsugatake (YAT), Kakioka (KAK), and Kanozan (KAN) Observatories and also those at YAT and KAN relative to KAK. It should be noticed that the secular change of total intensity at KAN relative to KAK is characterized by a generally increasing trend. Such a trend is in good harmony with the trend of secular change observed in the Tokai area relative to the Yatsugatake Observatory. However, after 1977 the trend changed from an increasing to a decreasing one in the Tokai area, while the secular change at KAN relative to KAK still continues to increase. This point will be discussed in the next section.

It would not be too crude to approximate the trend observed in the Tokai area during the period from 1971 to 1976 by a linear trend of

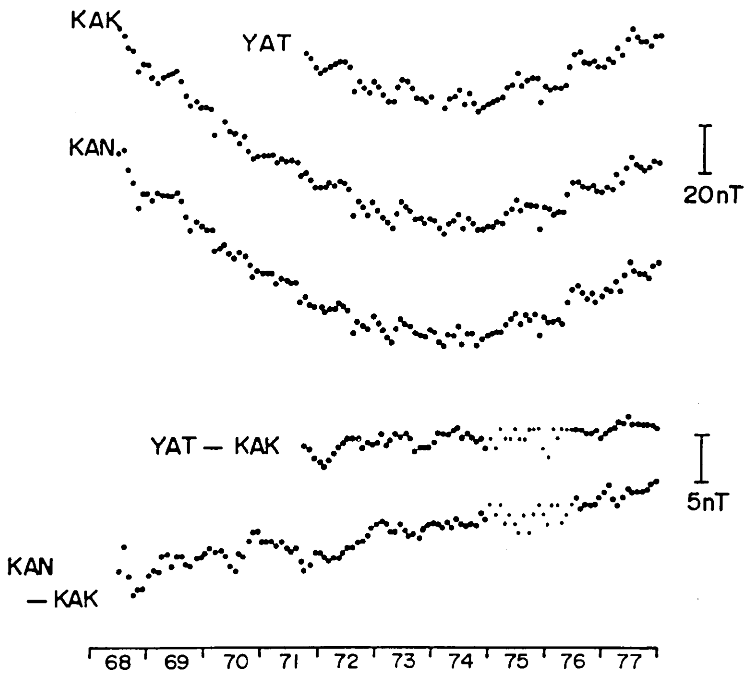

Fig. 8. Secular changes of total intensity at the observatories: Yatsugatake(YAT), Kakioka(KAK) and Kanozan(KAN). The differences between YAT and KAK and between KAN and KAK provide secular changes at YAT and KAN relative to KAK.

increase. The secular change at KAN relative to KAK can also be approximated by a similar linear trend. Thus, from the comparison between the two it seems possible to examine whether the secular change observed in the Tokai area is anomalous in the sense that it is the one peculiar to the Tokai area.

SASAI and ISHIKAWA (1976) estimated an average secular change at KAN relative to KAK for the period from 1968 to 1976 as 0.877 ± 0.078 nT/yr by making use of the least square method, since the change can be characterized by a linear trend. As can be found from Fig. 8, such an average secular change can also be applied approximately to the period from 1971 to 1976. Similarly average secular changes at each survey area (I—IV) relative to the Yatsugatake Observatory could be obtained for the period from 1971 to 1976 as

$$
\begin{aligned}
\text{I}: &\ 0.51 \pm 0.10 \text{ nT/yr} \\
\text{II}: &\ 1.04 \pm 0.23 \text{ nT/yr} \\
\text{III}: &\ 1.27 \pm 0.22 \text{ nT/yr} \\
\text{IV}: &\ 1.50 \pm 0.20 \text{ nT/yr}
\end{aligned}
$$

In the above results, the data of 1973 were not used because of their deviation from the linear trend. However, the results are not different very much from those obtained from all the data.

From the above results, the dependence of secular change on the latitude difference between two areas can be examined as shown in

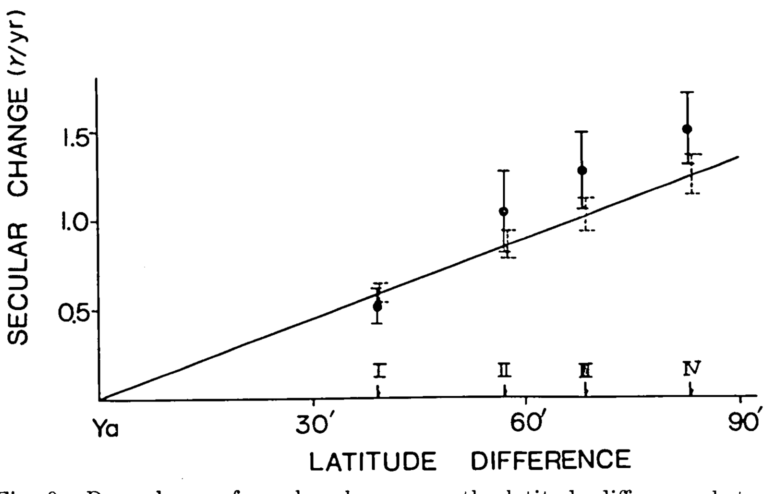

Fig. 9. Dependence of secular changes on the latitude difference between the survey area and the reference station. Details are given in the text.

Fig. 9. Solid circles and solid bars indicate the average secular changes in nT/yr(γ/yr) and their standard deviations, respectively, for each survey area. The straight line denotes the dependence of secular change on the latitude difference as obtained from the secular change at KAN relative to KAK. Dashed bars denote possible fluctuations of secular change to be expected at each location. If one takes error bars into account, it is not concluded that the secular changes of total intensity observed in the Tokai area are anomalous ones of crustal origin.

7. Discussion and concluding remarks

At most of the sites in the survey area, secular changes in the total intensity relative to the reference station, the Yatsugatake Observatory, have been less than 2 nT/yr. If the criterion as set by TAZIMA (1968) is applied to the present case, it is concluded that no anomaly in the geomagnetic field has been found in the Tokai area. However, this criterion may not be justified at present, since such a large secular change as 2 nT/yr results in a change of 20 nT or thereabouts in only ten years. A change larger than 10 nT has seldom been observed even at the time of an earthquake occurrence. As far as changes in magnetization of crustal rock due to a stress change are concerned, it is likely that geomagnetic changes during a relatively short period before an earthquake are smaller than at the time of its occurrence. If such a discussion is taken into consideration, one cannot deny the possibility that the observed secular changes reflect something anomalous in the Tokai area.

In the meantime, a similar secular change was also observed in another area and, therefore, the changes in the Tokai area are unlikely to be anomalous ones peculiar to this area. Such a regional change seems to have its origin in the spatial dependence of the secular change due to drifting non-dipole fields and/or due to fluctuations in the equatorial ring current system in the magnetosphere. However, the change in the trend of secular changes found only in the Takai area might not be ascribed to the origin mentioned above. It may possibly be of crustal origin and such a possibility should be examined by carrying out a more intensive survey in the Tokai area.

In general, however, it is no easy matter to distinguish secular changes of crustal origin from those arising from the other sources mentioned above. On the basis of large amounts of data obtained during the period from 1968 to 1973 at an array of geomagnetic observatories in Japan, HONKURA and KOYAMA (1976) examined the spatial dependence of secular changes and pointed out that the reference station should be located as close to the survey area as possible; shorter than 80′ in longitude and 30′ in latitude in order to avoid secular changes of non-crustal origins exceeding 0.3 nT/yr. In the present case, such a condition is not satisfied. Unless the condition is satisfied, it is necessary that there exists in an area relatively close to the survey area a distribution of stations suitable for examining the spatial dependence of secular changes, as was the case for the Tokai area. Otherwise, whether an observed secular change is anomalous or not should be carefully judged.

A more serious problem in the present survey system has been the spatial dependence of short-period geomagnetic variations. This effect is so large that in most cases secular changes observed at individual sites have not been considered to be very reliable. This is the reason why only the average secular change for each survey area has been considered. However, the effect can easily be removed by setting up in each survey area a temporary station for continuous measurements of the total intensity. Since short-period variations can be considered to be spatially uniform within each survey area, the difference in the total intensity between a survey site and the temporary station should be free from the above effect. Then the difference between the site and the reference station can be obtained by making use of the difference between the temporary and reference stations which can be determined from a large amount of good quality data.

It is certainly preferable that stations for continuous measurements be established in each survey area. In such a survey system two kinds of results will be obtained; local anomalies with their spatial extent covering only a few sites and regional ones presumably also containing secular changes of non-crustal origins. A local anomaly is likely to be of crustal origin and would be associated with a process of local nature in the crust. The possibility that a regional anomaly is associated with a large-scale crustal phenomenon can be examined on the basis of the means described in this paper.

In view of the possibility of an occurrence of a great earthquake in the Suruga Bay area, it is certainly an urgent matter to establish stations for continuous measurements in the survey areas IV and II. These stations should be combined with the station already established at the western coast in the Izu Peninsula by the Kakioka Magnetic Observatory group. Such an array of continuous stations should also be linked to a suitable reference station. A survey system consisting of a number of survey sites and some continuous stations is expected to provide important information on tectonic processes in the crust beneath the Tokai area.

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20. 東海地方における全磁力測量 (1): 1971年から1978年までの期間の経年変化

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筆者らは，1971年以来，東海地方において全磁力測量を実施してきた。この地方では直流電化線からの迷走電流による磁気ノイズが大きく，磁気点選定は容易ではないが，1979年現在，20点の磁気点を維持している。それぞれの磁気点では，携帯用プロトン磁力計を用いて，1分ごとに 10-20 分間全磁力を測定している。測定値は，基準点としての八ヶ岳観測所の全磁力と比較する。こうして，基準点に相対的な東海地方における全磁力経年変化を調べることができる。

1971年から1979年の始めまで，13回測量を行った。しかし，測点の一部でしか測定が行われていない時もある。この地域の地磁気短周期変化異常のために，測点と基準点との間の全磁力差は精度よく求められない。したがって，2～3点でしか観測されないような局所的異常は，その異常がかなり顕著である場合以外は，現在の観測システムでは検出できない。東海地方に予想される地震に関連する異常域はかなり広いと思われるので，地域的異常の検出に重点を置くことにした。そのために，測量域を4つに分け，それぞれの測量域内の測点で得られた経年変化の平均をもって，地域的経年変化とした。

1971年から1978年までの結果では，最大 1.5nT/yr に達する経年変化が得られた。このような変化には，4つの測量域に共通のパターンが存在し変化量は南方程大きいという，顕著な傾向が見られる。こうして東海地方においては，経年変化は測量域と基準点との緯度差に依存することがわかった。しかし，同様の依存性は関東地方においても見られることがわかったので，東海地方で観測された経年変化が地殻に起因する異常であるとは結論できない。このような経年変化の緯度依存性は，地球の核あるいは磁気圏に原因のある経年変化の空間依存性によるものであろうと思われる。