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Time Changes of Transfer Functions at Kakioka Related to Earthquake Occurrences (II)

By

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Abstract: In this paper, earthquake precursor changes of transfer functions at Kakioka are statistically re-examined in detail on the basis of a more reasonable selection of earthquakes than in the previous paper.

From the present re-examinations, the earthquake precursor changes in transfer functions are more clearly confirmed than in the previous study, especially in short-period components such as 10, 20, 30, 60 minutes. Furthermore, the present results are also confirmed in general features from the same analyses for other transfer function data by the method of power spectral analysis which is different from the present one of the Fourier transform analysis and the least square method.

As another new feature in time change of transfer functions, certain kinds of periodic changes with a periodicity of about 27–79 days are suggested in longer-period components than 60 minutes.

1. Introduction

In the previous paper, Part I of this series (Sano, 1980), the analysis method of transfer functions at Kakioka by using the data from the KASMMER system (optical pumping magnetometers) was described, and preliminary results mainly concerning time changes of the transfer functions were reported. (Hereafter, the term of transfer function is simply denoted by T-function.) As introduced in Part I, Yanagihara (1972) and Yanagihara and Nagano (1976) reported that there existed the time changes of T-functions at Kakioka closely related to neighbouring earthquake occurrences. Also, from the present author's previous study, a certain existence of some earthquake precursor changes of various kinds of T-functions was somewhat confirmed in many individual events of remarkable earthquakes, and was clearly confirmed with reference to the statistical features of many large earthquakes near Kakioka (Magnitude M=4–6). In addition to the above changes, some geomagnetic activity dependences in time change of T-functions were found.

Meanwhile, there remained several important questions on the earthquake precursor change of T-functions in the previous preliminary study. They are summarized as follows:

(1) Whether or not features of earthquake precursor changes in T-functions are different for different locations of earthquake epicenters.

(2) Whether or not the features are different among the four kinds of T-functions, Au, Av, Bu, Bv (Details of T-functions should be referred to Part I.), or among seven period components analyzed in the present paper.

(3) Whether or not the earthquake precursor changes detected by the present author can be confirmed from other T-function data which were obtained by a different method of power spectral analysis using the same KASMMER's geomagnetic data by Shiraki (Shiraki, 1977).

This paper will present some additional results for the above-mentioned questions by re-analyses of the same data during the period from Mar. 1977 to Dec. 1978 as in Part I. It has also been one of the most important questions whether or not the selection of earthquakes treated in Part I was reasonable. Then, the present re-analyses are carried out according to more reasonable selections of earthquakes with various conditions of the magnitude and the location of earthquakes than in Part I. The analysis method is the same as the superposed epoch method with a weighted mean and a smoothing of the five-term running mean used in Part I. For details see Part I.

Hereafter the long term "earthquake" will be shortened to "Eq".

2. Data analyses

2.1 Transfer functions

T-functions in the present paper were obtained by the technique of the Fourier analysis and the least square method for a number of geomagnetic short-period variations. The periods treated in the present paper are as follows:

10, 20, 30 and 60 minutes (These are called short-period or S. P. band.)

90, 120 and 180 minutes (These are called long-period band or L. P. band.)

5 and 240 minutes (These are not analyzed in this paper.)

As for the weight in the weighted mean calculation by the superposed epoch method, in Part I the reciprocal of standard deviation (SD) assessed in the calculation of individual T-functions was simply used, while in this paper the following weight is adopted as an attempt to reduce contributions from unreliable data more severely than in the previous study.

$(SD_0/SD)^2$; when SD is larger than SD_0.

$\sqrt{SD_0/SD}$; when SD is smaller than SD_0.

Here, SD_0 is a threshold value of SD, being experimentally taken to be 0.050.

2.2 Earthquakes (Eq's)

In order not only to confirm certain Eq-precursor changes in T-functions at Kakioka but also examine their differences in the manner of change for different Eq-locations, in this paper the Eq-area near Kakioka is divided in two ways, and Eq's are selected from each division. As shown in Fig. 1, one way is the division into a Land area and an Ocean area. The former consists mainly of the southern part of Ibaraki Pref. and the northern part of Chiba Pref. The latter consists of the ocean area off Ibaraki, Chiba and Fukushima. The outer boundary of the Ocean area is an arc every part of which is about 200 km away from Kakioka. The whole of this division is named Region A. The other way is by dividing into two circle areas-one which lies within a distance of 60 km from Kakioka and the other which lies between the distances of 60 km and 120 km from Kakioka except a part of the land area outside the boundary as shown in Fig. 1. These areas are named Circle area I and Circle area II, and they together form Region B. The Eq-areas of our present concern are closely related to the so-called Pacific

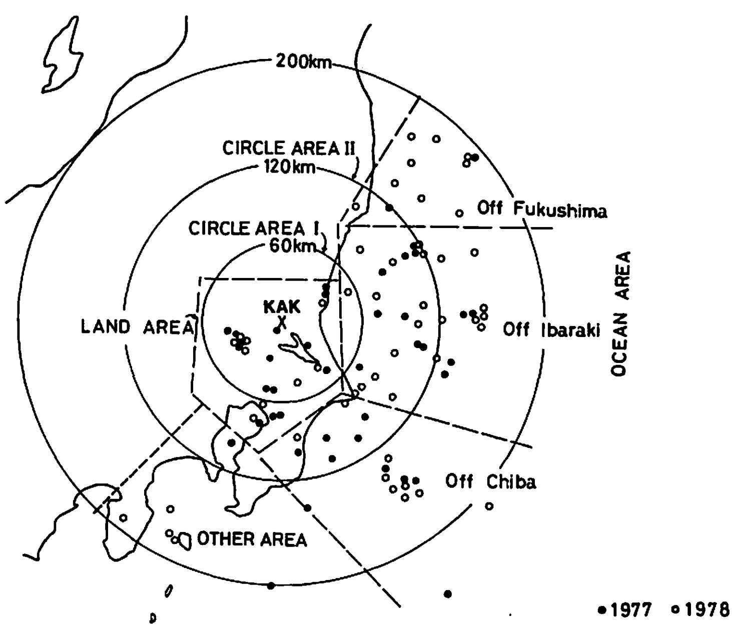

Fig. 1. Various earthquake areas treated in this paper and epicentral distribution of the earthquakes larger than $M=3.9$ during the period from Mar. 1977 to Dec. 1978.

Ocean Plate. Those related to the so-called Philippine Sea Plate are given a little consideration in this paper.

Table 1. List of selected earthquakes in the four earthqauke areas.

	Date		Time		Location	Depth	Dis.	Mag.	Remarks
Land area, Nq=18	1977		h	m		km	km		
	Mar.	30	08	45	Central Ibaraki Pref.	70	8	4.4	
	Apr.	19	15	15	Coast of Ibaraki Pref.	60	42	5.1	
	May	3	21	54	N Chiba Pref.	80	50	4.3	○
	〃	13	19	27	Central Chiba Pref.	70	72	4.4	
	Jun.	4	08	27	N Tokyo Bay	60	78	4.6	
	〃	16	23	51	SW Ibaraki Pref.	50	32	4.4	○
	Aug.	21	00	26	〃	70	28	4.1	○
	Oct.	5	00	39	〃	60	35	5.4	○
	Nov.	4	20	17	〃	50	36	4.2	○
	〃	16	23	58	S Ibaraki Pref.	90	26	4.6	○
	1978								
	Jan.	25	08	23	Ibaraki-Chiba border	40	45	4.1	○
	Feb.	17	21	51	SW Ibaraki Pref.	60	33	4.3	○
	Mar.	20	19	24	〃	60	36	5.5	○
	May	26	03	18	N Tokyo Bay	60	76	4.2	
	Jun.	5	21	17	SW Ibaraki Pref.	50	34	4.2	○
	Jul.	5	14	08	Coast of Ibaraki Pref.	60	48	4.1	○
	Aug.	13	22	23	N Tokyo Bay	80	68	4.7	
	Oct.	19	19	07	N Chiba Pref.	60	50	4.2	○
	Mean					62.8	44.3	4.49	
Region B, Nq=12	1977								
	Jun.	4	08	27	N Tokyo Bay	60	78	4.6	
	〃	22	16	11	E Off Chiba Pref.	40	97	5.0	
	Aug.	7	08	43	〃	40	106	4.7	
	Oct.	5	00	39	SW Ibaraki Pref.	60	35	5.4	
	〃	26	06	55	Off Ibaraki Pref.	30	96	4.7	
	Nov.	16	23	58	S Ibaraki Pref.	90	26	4.6	
	Dec.	17	00	10	Off Ibaraki Pref.	50	87	5.6	○
	1978								
	Mar.	20	19	24	SW Ibaraki Pref.	60	36	5.5	
	Apr.	8	01	21	Near Choshi	60	80	4.8	
	Jun.	5	03	40	Off Ibaraki	50	76	4.8	
	Aug.	13	22	23	N Tokyo Bay	80	68	4.7	
	Sep.	2	08	37	Near Choshi	30	90	4.6	
	Mean					54.2	72.9	4.93	

(to be continued)

Adding to the earthquakes marked by ○ in the above lists.

Circle area I, Nq=16	1977							
	Oct.	27	02	48	SW Ibaraki Pref.	60	42	4.1
	1978							
	Apr.	10	19	48	Off Ibaraki Pref.	50	57	4.3
	Aug.	13	05	48	SW Ibaraki Pref.	50	32	4.1
	Mean					58.8	41.9	4.47
Ocean area, Nq=17	1977							
	May	20	04	20	E Off Chiba	60	96	4.3
	Jun.	5	20	05	Off Ibaraki Pref.	30	133	4.6
	〃	22	16	11	E Off Chiba Pref.	40	97	5.0
	Aug.	7	08	43	〃	40	106	4.7
	〃	21	14	19	〃	40	158	5.4
	Sep.	11	08	10	Off Ibaraki Pref.	40	116	4.3
	Oct.	22	20	58	〃	40	110	4.9
	Dec.	17	00	10	〃	50	87	5.6
	1978							
	Jan.	21	11	17	Coast of Ibaraki Pref.	80	38	4.4
	Mar.	8	19	27	Off Ibaraki Pref.	40	90	4.3
	Apr.	7	08	30	E Off Chiba	30	170	6.1
	〃	27	21	01	Off Ibaraki Pref.	40	100	4.4
	May	13	07	47	〃	40	125	5.2
	Jun.	5	03	40	〃	50	75	4.8
	Jul.	27	22	29	〃	30	154	5.1
	Sep.	2	08	37	Near Choshi	30	90	4.6
	Oct.	13	13	37	〃	30	80	4.4
	Mean					41.8	107.4	4.83

Dis. =Epicentral distance from Kakioka
Mag. =Magnitude of earthquake
Time=JST

Shown in Fig. 1 are the epicenters of Eq's with magnitudes larger than 3.9 in the whole area of the above-mentioned two divisions. Several ones located outside the Eq-area of our present concern are plotted for reference' sake, because they are very remarkable Eq's that occurred during this period.

To confirm statistically Eq-precursor changes of T-functions in various cases, 12–18 Eq's whose magnitudes are larger than a threshold value are selected from the respective Eq-areas. In this paper are treated groups of Eq's from the Land area, Ocean area, Circle area I and Region B. The threshold values are different in each group, being $M=4.0$ for the Land area and Circle area I, $M=4.2$ for the

Ocean area and $M=4.5$ for Region B. Though there is no special meaning in the determination of the various threshold values, it is generally intended to select larger Eq's from wide Eq-areas than small ones. The Eq's selected and their details are given in Table 1.

As for the Eq-data, the following two kinds of superposed occurrence frequencies are calculated. One is only for some selected Eq's and the other is for the whole of Eq's larger than $M=3.4$ in each Eq-area. The latter Eq-occurrence frequency is calculated to express a general seismic activity. To express the Eq-occurrence frequency related to the precursor change of T-functions, it may be necessary to consider certain kinds of weighted occurrence frequencies whose weight must be a function of the Eq-magnitude and the distance of the epicenter. In this paper, $e^{(M-3.8)}$ is simply used as a weight of an Eq ignoring the function of epicentral distance, though it is uncertain whether or not this is the best way.

On the other hand, from a different point of view, the occurrence frequency of Eq's in a large Eq-area which consists of Region A and other area shown in

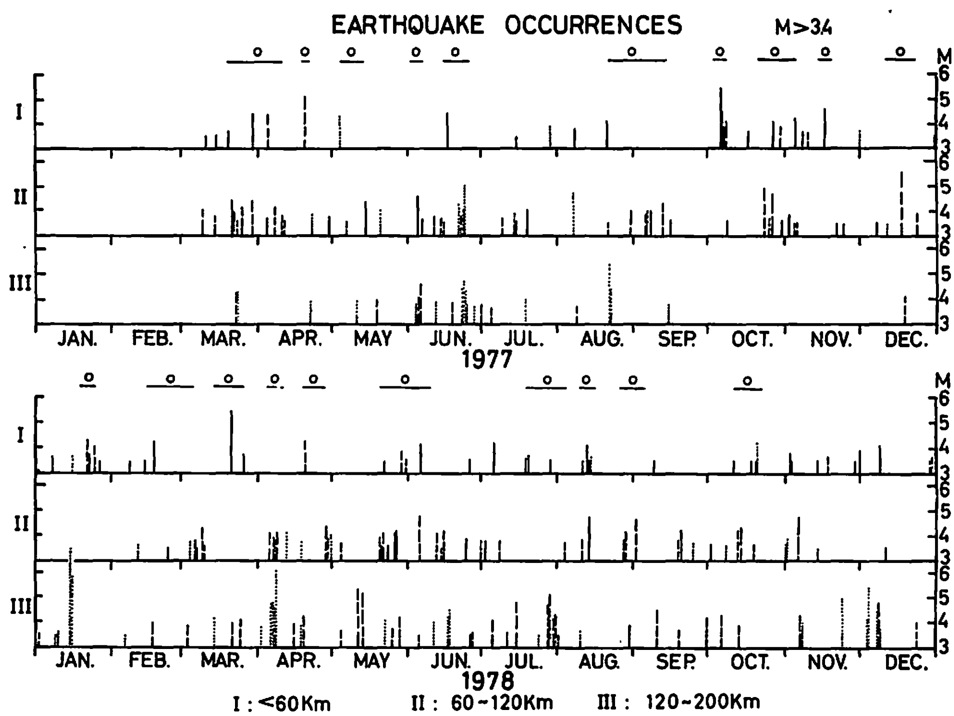

Fig. 2. Time series diagram of earthquake occurrences in three circle areas (I, II and III) neighbouring Kakioka. The horizontal lines indicate 20 seismically active epochs and the mark ∘ is the central day of these epochs.

Fig. 1 is examined in order to see the general tendency of seismic activity for this large area. Fig. 2 shows time patterns of Eq-occurrences in three circle areas into which the large Eq-area is divided according to the distance from Kakioka as noted in the figure. All the Eq's larger than $M=3.4$ in each Eq-area are shown by three kinds of bars each of whose lengths is proportional to its magnitude. The full, broken and dotted bars indicate the Eq's within the Land area, the northern Ocean area (off Ibaraki and off Fukushima) and the southern area (off Chiba and other area), respectively.

From this diagram 20 seismically active epochs, which are shown by the horizontal lines, are picked up. The central days of these epochs are indicated by the mark ○ on the horizontal lines. Since the 20 epochs were determined by eye-estimation, it may be questionable whether or not there is general reasonableness in their selection. In any case, for reference' sake, the same superposed epoch analyses are made for these 20 days, too.

2.3 Geomagnetic activity (K-activity)

The geomagnetic activity data are the same as those in Part I, being the mean of the daily sums of K-index ($\sum K$) at Kakioka for the period from which about ten geomagnetic disturbances were selected to determine a set of individual T-functions. Of course, these geomagnetic activity data are analyzed by the same superposed epoch method. Hereafter, the geomagnetic activity will be named by K-activity.

3. Mean earthquake time changes of transfer functions and related phenomena

In this section, various mean Eq-time changes of T-functions and related phenomena superposed for the selected Eq's in the four Eq-areas and for the 20 seismically active epochs are presented. The Eq-time changes of T-functions were basically obtained for the S. P. and the L. P. band and for both bands (denoted by All band).

3.1 Mean earthquake time changes based on the selected earthquakes

a) For the earthquakes in the Land area and in the Ocean area

Fig. 3 presents the results for the Eq's selected from the Land area and the Ocean area. The left (a) and the right (b) panel are mean Eq-time changes of T-functions of three bands superposed for the 18 Eq's in the Land area and the 17 in the Ocean area, respectively. Those indicated by large dots connected with thick lines are all means of Au, Av, Bu, Bv T-functions in each band. The

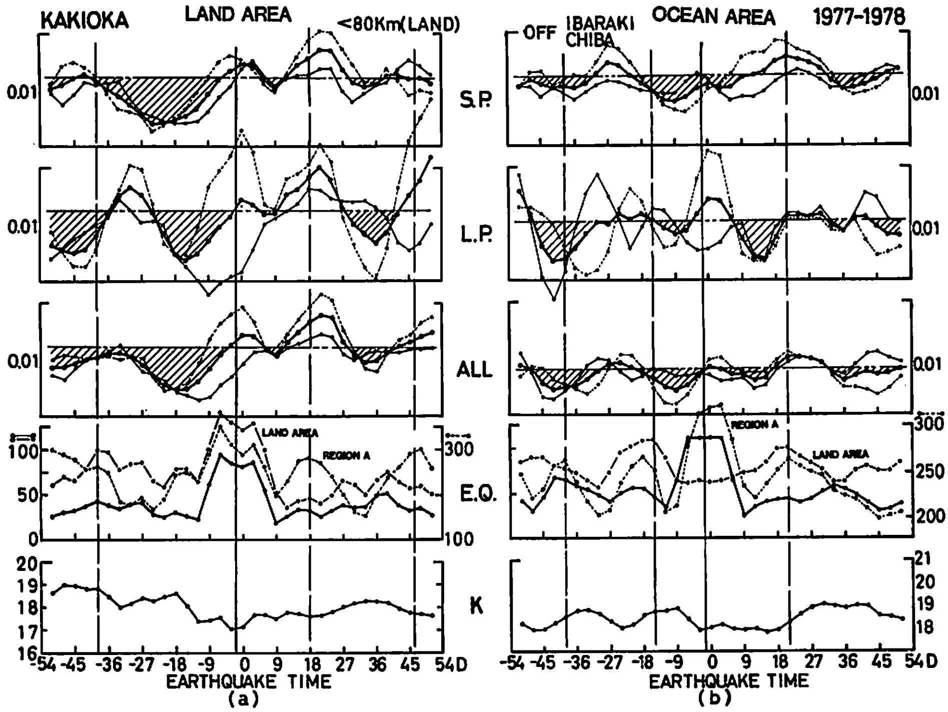

Fig. 3. Mean earthquake time changes of transfer functions of three bands (S. P., L. P. and ALL) averaged for 18 selected earthquakes in the Land area (panel a) and for 17 ones in the Ocean area (panel b). E. Q: Superposed earthquake occurrence frequencies, K: Mean geomagnetic activity change.

accompanying ones indicated by thin full or dotted lines with small dots are those of the real Au, Bu T-functions and the imaginary Av, Bv T-functions. The lower two plots in each panel are of the Eq-occurrence frequencies (E. Q.) and the K-activity (K). Each full thick line of E. Q. is the occurrence frequency superposed only for the selected Eq's in each area. The dotted or broken lines are those for all Eq's larger than $M=3.4$ in the Eq-areas noted in the figure. These are presented to check some of the contributions of Eq's other than the selected ones in time change of T-functions. The vertical lines indicate respective major maximum peak and a few secondary minor peaks of the Eq-occurrence frequency. The epicenters of the selected Eq's in both cases are shown in Fig. 4. The mean magnitudes of these selected Eq's are 4.49 for the Land area and 4.83 for the Ocean area, respectively.

As can be seen in Fig. 3, in general all kinds of Eq-time changes of T-functions show considerably complicated behaviours especially in the L. P. band in each case.

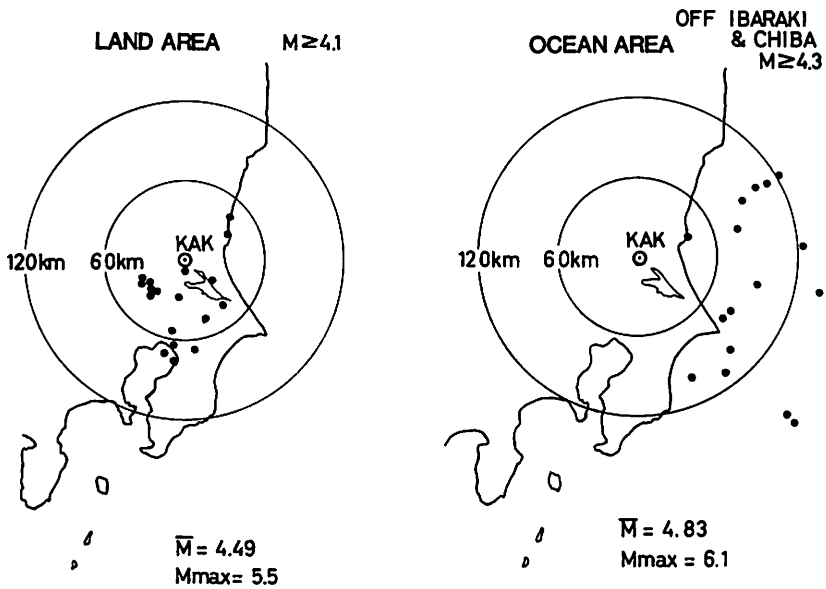

Fig. 4. Epicentral distributions of the selected earthquakes treated in Fig. 3.

And their behaviour is widely different between the Land area and the Ocean area. However, if we pay the attention to all mean Eq-time changes shown by the thick lines, we can find the following meaningful features probably related to the Eq-occurrences.

First, from the case of the Land area it can be somewhat clearly found that meaningful decreasing changes in T-functions indicated by hatching appear corresponding to the respective peaks of the Eq-occurrence frequency, though their amplitudes are very small, amounting to no more than 0.01. In the case of S. P. band or All band, the predominant major decreasing changes of T-functions can be seen before the central major peak of the Eq-occurrence frequency and three other minor secondary changes can be seen corresponding to the secondary peaks of Eq-occurrence frequency. The central major decreases of the Eq-time change of T-function for Eq's occurring in this case are reliable with a 95% confidence judging from the calculated standard errors of respective plots, though the errors are not shown in this paper.

On the other hand, the Eq-time changes of T-functions are not considered to relate so closely to the change of K-activity (K) shown at the bottom of the panel. As reported in Part I and will be discussed in a later section, there are some K-activity dependences in time change of T-functions. Their effects cannot be entirely ignored even in the present case.

In this way, we can understand that the Eq-time changes of T-functions, or at least the major decreases preceding the central major peak of Eq-occurrence frequency, may have the character of Eq-precursor change mentioned in Part I. In particular, that in the S. P. band or All band may be regarded as a clear Eq-precursor change.

As for the Eq-time change in the L. P. band, though its magnitude is generally greater than that in the S. P. band, the main parts of the conspicuous decreasing changes shown by hatching cannot be so well explained only by Eq-precursor changes as in the S. P. band. These changes in the L. P. band having a poor correlation with the changes of Eq-occurrence frequency, they may suggest the possibility that there are certain time changes in T-functions caused by some unknown origins other than the Eq-precursor effect and, of course, the K-activity dependence. This fact will further be clearly suggested by another case (Fig. 5).

Second, from the Eq-time changes for the Eq's in the Ocean area (the right

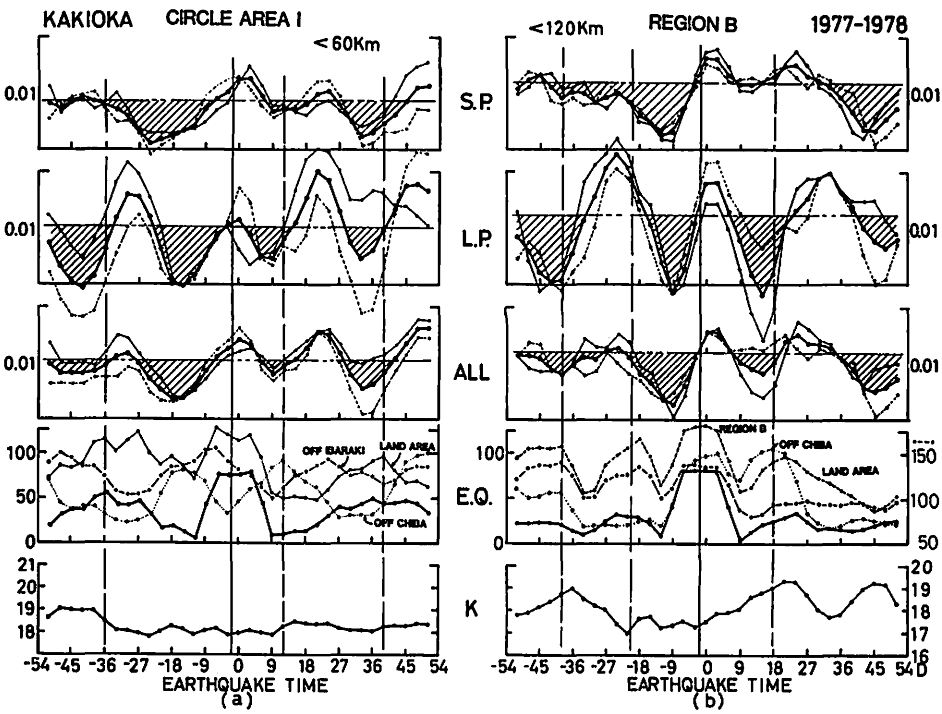

Fig. 5. Mean earthquake time changes of transfer functions for 16 selected earthquakes in the Circle area I (panel a) and for 12 ones in Region B (panel b). The other notes are the same as in Fig. 3.

panel), such clear Eq-precursory changes as those for the former case cannot be identified. In particular, the Eq-time change in the L. P. band does not show any clear relation to the Eq-occurrence frequency or the K-activity. A slight Eq-precursory change seems to occur in the S. P. band or All band, though its magnitude is very small, being about half of that of the former case. The changes is weak but the existence of Eq-precursor changes is never denied even for Eq's in the Ocean area.

These facts may be regarded as natural consequences of weak precursor effect of distant Eq's and an imperfect elimination of relatively strong precursor effects of near Eq's such as those in the Land area. Namely, this means that the Eq-precursor effects from Eq's in the distant area (ocean area) are much smaller than those in the nearer area (land area).

b) For the earthquakes in the Circle area I and Region B

Next, in Fig. 5 are presented in the same manner as Fig. 3 two other results for the 16 Eq's in the Circle area I (One is located outside of this area.) and for the 12 Eq's in the Region B. The epicenters of these selected Eq's are plotted in Fig. 6. It should be remarked that two groups of the selected Eq's each include 5 common Eq's, because the Circle area I is part of the Region B. The mean magnitudes of the selected Eq's are 4.47 for the former and 4.93 for the latter.

The general features of the Eq-time changes of T-functions shown in Fig. 5

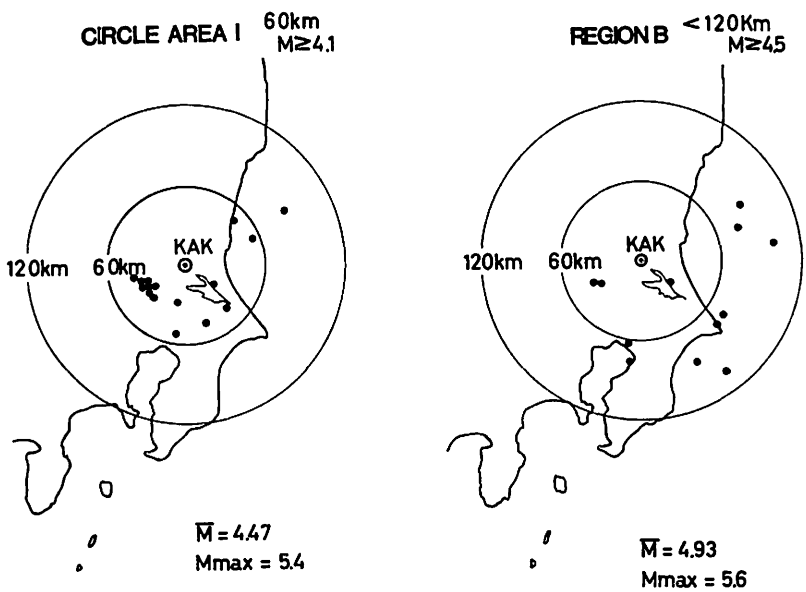

Fig. 6. Epicentral distributions of the selected earthquakes treated in Fig. 5.

are quite similar to those for the Land area of Fig. 3. Of course, both the S. P. band and the All band show clear Eq-precursor changes as well as those for the Land area of Fig. 3. This is a rather natural result, because the respective selected Eq's in the three areas, Circle area I, Region B and Land area, include many common Eq's; especially in the Circle area I and the Land area 12 Eq's are common.

As for the Eq-time changes in the L. P. band, they are not considered to be due only to the Eq-precursor effect as well as suggested in the former case of Fig. 3. It is strongly suggested that there exist certain kinds of periodic changes with a period of about 27–29 days in the T-functions of L. P. band, especially in the case of Region B (the right panel of Fig. 5).

Relatively large changes of K-activity (K) are found in the case of Region B. They may modify the Eq-time change of T-functions, particularly during the Eq-times from 9-day to 54-day. But it can hardly be considered that the K-activity dependences are the main origins of the Eq-time changes of our present concern.

The above facts, such as the existence of periodic change, are interesting results newly obtained from the present analyses, but their details will be examined in Part III of the present paper (Sano, 1982, in preparation).

c) Some other detailed features in the earthquake time changes of transfer functions

With respect to detailed features in the Eq-time changes of T-functions, it is very interesting to note that the changes of the real and the imaginary T-functions in the S. P. band generally show good coincidence in amplitude and phase, especially in the case of Region B, but those in the L. P. band show considerably great differences, especially in the case of the Land area. At present, there is no further fact to decide whether it was by mere chance or was caused by a meaningful mechanism which affects Eq-precursor changes themselves. Further detailed study on this fact is highly required.

Magnitudes of the Eq-precursor change of the S. P. band are nearly equal for the three areas, Land area, Circle area I and Region B, though the mean distance and the mean magnitude of Eq are fairly different between the former two areas and the last region as given in Table 1. The former two areas are small and near Kakioka and their mean magnitudes and mean distances of Eq's are 4.49, 44.3 km and 4.47, 41.9 km, respectively. The last region is wide but its mean magnitude and mean distance of Eq's are large, being 4.93, 72.9 km. Supposing that the magnitude of Eq-precursor change at Kakioka depends upon the two factors of magnitude and epicentral location of Eq's, differences in each factor cancel each other in the above-mentioned case and cause nearly equal changes. In other words, this result may reflect a difference in the precursor change for different epicentral locations of Eq's as well as the results in the cases of the Land area and the Ocean area.

3.2 Mean earthquake time changes based on 20 seismically active epochs

Similar mean Eq-time changes of T-functions and others superposed for the 20 epochs which were determined in Fig. 2 are presented in Fig. 7 in the same manner as Fig. 3. But the E. Q. plot connected by the thick line, which corresponds to those for the selected Eq's in former cases, is obtained by a different way, where degrees of Eq-activity estimated subjectively for the 20 epochs (days) are used instead of the weighted occurrence frequency of Eq's in superposing calculation. One of the five degrees of Eq-activity (1 to 5) is assigned to each epoch (day), considering the Eq-magnitude, the number of occurrences and the distance of the epicenter from Kakioka. The degrees of the other days are zero. The other E. Q. plots connected by the thin lines are the same kinds of Eq-occurrence frequencies as those in Fig. 3.

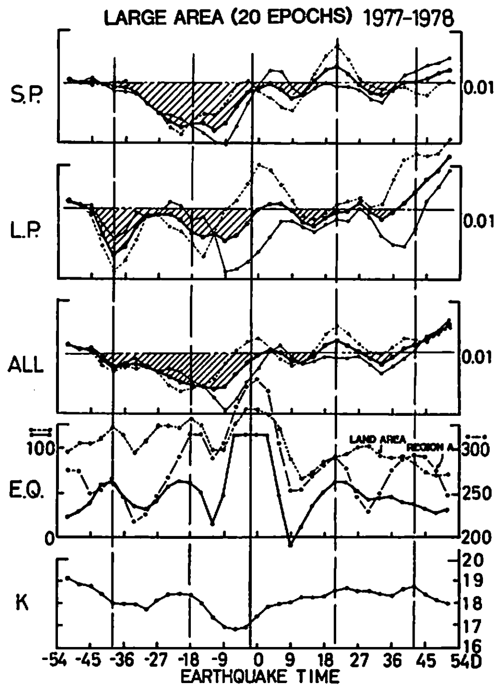

Fig. 7. Mean earthquake time changes of transfer functions for 20 seismically active epochs as shown in Fig. 2. The other notes are the same as in Fig. 3.

Also in this case, the general features of the time changes of T-functions are quite similar to those in the previous cases (Figs. 3 and 5). The present time changes of T-functions may be regarded as certain Eq-precursor changes as well as in the previous cases, because all the greatest peaks of seismic activity appear in the central part corresponding to the greatest decreasing changes of T-functions. This can be most clearly recognized in the case of S. P. band.

In addition, in this case it should be remarked that a relatively large decreasing change of the K-activity takes place around 6-day in Eq-time. Accordingly, some of its modifying effects on the time changes of T-functions must be taken into consideration. But these effects are not so large that the general features are changed by them, because they might produce in general an increasing change of T-functions in this case as will be discussed below. In any case, these modifying effects might more or less weaken the decreasing changes of T-functions. If we consider their corrections, the present precursor changes will be made much more significant. Besides, in the present case the time changes in the L. P. band do not show clear and large changes as those in the previous cases. This may mean that the periodic changes pointed out previously are well averaged out by accident.

3.3 Summarizing remarks in this section

From the various Eq-time changes for the Eq's selected in the various Eq-areas, the existence of Eq-precursor changes in T-functions at Kakioka have been recognized with more certainty than in Part I. And it has become to a certain extent possible to discuss their detailed features. For example, it has been found qualitatively that contributions of the Eq-precursor effect to the change of T-functions at Kakioka seem to be predominant from the Eq's in the near land area than from those in the far ocean area. And some significant differences in Eq-time change between the real T-functions and the imaginary ones especially in the L. P. band and between the S. P. and the L. P. band have been suggested.

Furthermore, it has newly been suggested that certain kinds of periodic time changes in T-functions perhaps not directly related to Eq-occurrences and K-activity changes seem to exist in the L. P. band. The reliability of the time change of T-functions presented in this section has been little discussed. The standard error values of the respective mean T-functions have been calculated, though they are not shown in this paper. Judging from these errors assessed for each plot in the figures of our present concern, almost all of the major time changes of T-functions are approximately equal to or a little over the 95 % confidence interval in amplitude of change. This was discussed in detail in Part I.

In the present cases the reliability of the time change of T-functions is essentially equal to that obtained in Part I.

4. Mean geomagnetic activity time changes of transfer functions

It was reported in Part I that there were complicated K-activity dependences in time change of T-functions which might be caused by certain external origins of the geomagnetic short-period variations. In order to examine such dependences again, the mean superposed time changes of T-functions and the other elements based on 18 disturbed days and 22 calm days were obtained by the same method as for the Eq-time change. The time change thus obtained is called here a K-activity time change. Results obtained are presented in Fig. 8 in the same manner as in Fig. 3. The left panel (a) and the right panel (b) are for the 18 disturbed days and for the 22 calm days, respectively.

As can be seen in Fig. 8, the respective K-activity time changes of T-functions and the corresponding K-activity show similar periodic behaviour as expected from

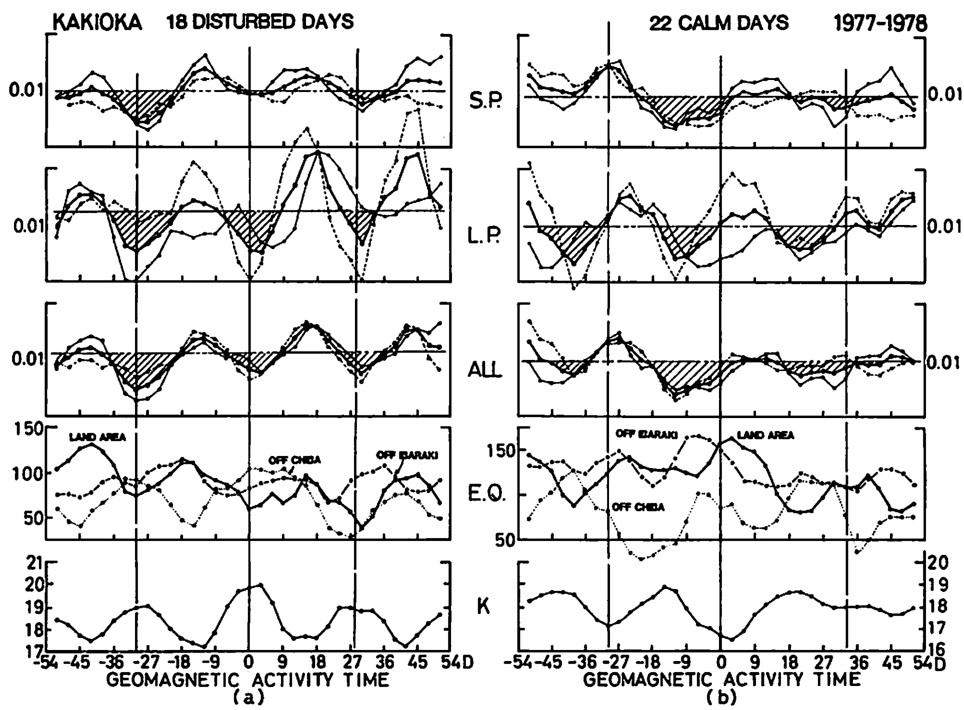

Fig. 8. Mean geomagnetic activity time changes of transfer functions of three bands (S. P., L. P. and ALL) based on 18 disturbed days (panel a) and for 22 calm days (panel b). The other notes are the same as in Fig. 3.

the recurrence of the K-activity and the K-activity dependences in time change of T-functions reported in Part I, particularly, in the case of the left panel. However, no good proportionality can be recognized between their amplitudes, although a good reverse-phase relation can be found. For example, the decreases of T-functions at the highest K-activity around the 0-day of the left panel are not so large but are smaller than the others corresponding to the secondary maximum of the K-activity.

With respect to the Eq-occurrence frequency (E. Q.), those for the Land area shown by the thick lines indicate similar periodic changes to those of T-function or the K-activity, but the others for other Eq-areas are characterized by slightly different periodic changes. These features can be much more clearly found from the panel (a) than from the panel (b). The respective amplitudes of T-function changes in the All mean (All) are rather well proportional to those of the Eq-occurrence frequency changes in the Land area. Their phase relation is such that the decreasing changes of T-functions take place before the respective peaks of the Eq-occurrence frequency as if the former were just an Eq-precursor change mainly related to the Eq's in the Land area.

From these facts it may be more reasonable to consider that the principal parts of the K-activity time changes of T-functions are regarded as some Eq-precursor changes rather than changes themselves due to the K-activity dependences. Namely, though the present periodic changes of T-functions contain certainly minor parts produced by the K-activity dependences, their major parts may be due to the Eq-precursor effects. Particularly, the central decreasing change of T-functions for the case of the 22 calm days can be regarded as an Eq-precursor change, because during its recovery (increasing) phase all of the Eq-occurrence frequencies indicate a predominant peak.

After all, it may be concluded from the above that the K-activity effect on the time change of T-functions is rather smaller than the Eq-precursor effect or others, at least in its statistical features. This is supported by or derived from the fact that any predominant changes depending upon the K-activity were not found in the Eq-time changes of T-functions discussed in the preceding section. In any case, it is very interesting that all the phenomena of our present concern have some close relations in periodic change behaviour to one another. In addition to an examination of the periodic change of T-functions as previously mentioned, similar examinations of Eq-occurrences and the K-activity will also be done in detail in Part III of this series (to be published).

5. Confirmations of the present results by independent different data of transfer functions obtained by the power spectral analysis method

As introduced in the first section, T-functions of 20-, 30- and 60-minute period components at Kakioka have been obtained very frequently (day by day) using the power spectral analysis method by Shiraki (1977). It is very meaningful to examine whether or not the present results can be confirmed by the same analyses of Shiraki's data, too. These examinations have been done by the present author with Shiraki's cooperation in offering the data.

Four examples of results obtained are shown in Fig. 9. They represent comparisons of the Eq-time changes by the present author's data with those by Shiraki's in the four cases of Region B, Circle area I, Land area and 20 seismically active epochs. The T-function changes (T. F.) shown in Fig. 9 are all mean Eq-time changes for the 20-, 30- and 60-minute period components and for all T-functions. Those indicated by full lines and those by dotted lines are based on

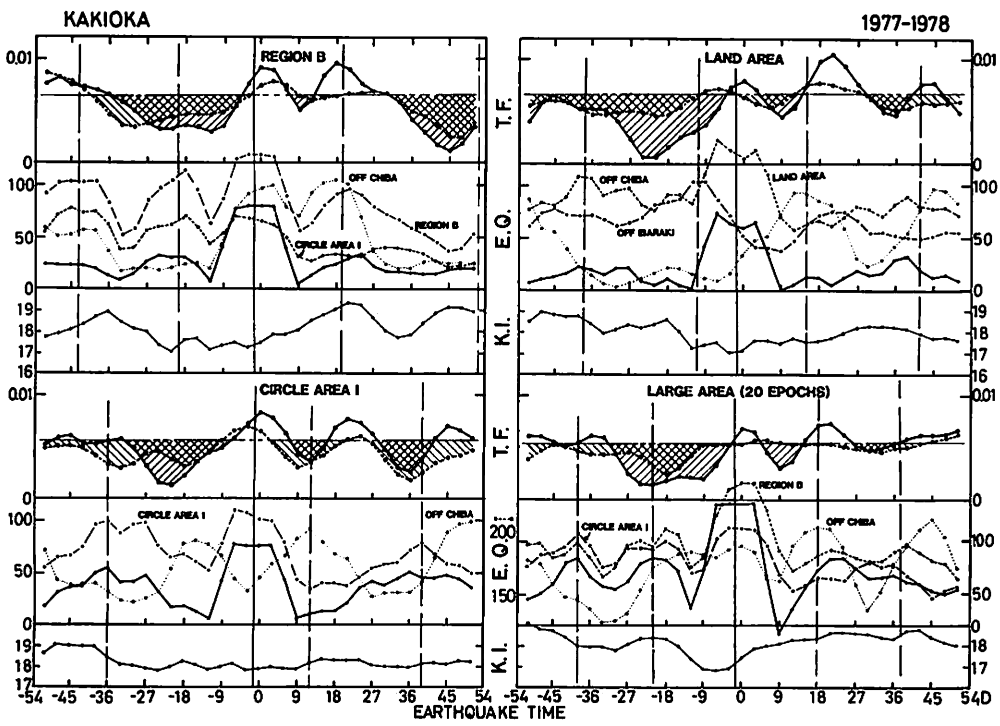

Fig. 9. Comparison between the earthquake time changes of transfer functions obtained from the present author's data (T. F. shown by full lines) and those from Shiraki's (shown by dotted lines) in four cases.

the present author's data and Shiraki's, respectively. The other plots concerning the Eq's and the K-activity are the same as the corresponding ones shown in the previous section.

Two kinds of the Eq-time changes of T-functions in each case are coincident in general features as shown by hatching. However, minor features are more or less different from each other. The amplitudes of changes by Shiraki's data are in general smaller than those by the present author's, and some differences in phase or shape between them are recognizable. In this way, though there are differences in details, it is highly noteworthy that the Eq-precursor changes which are consistent with those by the present author's data were confirmed by Shiraki's T-function data. At least, the two results are never inconsistent.

A similar comparison has been carried out for the K-activity time change of

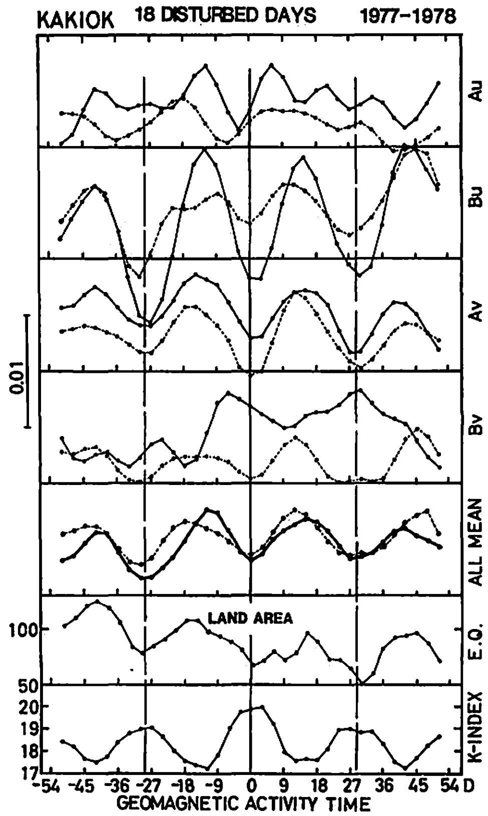

Fig. 10. Comparison between the mean geomagnetic activity time changes of transfer functions obtained from the present author's data and Shiraki's for the 18 disturbed days. The others are the same as in Fig. 8.

the 18 disturbed days. Its result is shown in Fig. 10. Respective plots of T-functions are the mean K-activity time changes of Au, Bu, Av and Bv, and all mean (ALL MEAN) from the uppermost. Those connected by full lines are based on the present author's data and those by dotted lines are based on Shiraki's. The Eq-occurrence frequency (E. Q.) and the K-activity (K-index) are the same as those in Fig. 8.

The changes in each kind of T-function are more or less different from each other, except those in Av T-function. Particularly, those in Bv T-function are opposite to each other in sense of change. However, the changes in ALL MEAN show a good coincidence not only in amplitude but also in phase. Though the above complicated features in each kind of T-function cannot be well explained, it is notable that such good coincidence is found in ALL MEAN.

6. Concluding remarks

The detailed re-analyses on the time changes of T-functions at Kakioka related to the Eq-precursor have been carried out in this paper according to more reasonable selections of Eq's. From these re-analyses time changes that look like the Eq-precursor change have been more clearly confirmed than Part I. In addition to the above, the present results have been consistently supported in general features from the same analyses for the independent T-function data obtained by the power spectral analysis method.

Thus it becomes possible to conclude with much more certainty that there exists an Eq-precursor in time change of T-functions at Kakioka for neighbouring Eq's with $M=4$–6. The main results concerning the Eq-precursor are as follows:

(1) The Eq-precursor change in T-functions can be detected much more clearly or reasonably in the S. P. band than in the L. P. band.

(2) The Eq-precursor change seems to be larger for Eq's near Kakioka than for those in the far ocean area.

(3) The Eq-time changes obtained here in the S. P. band are considerably similar in the manner of change between the real and the imaginary T-function, but in general those in the L. P. band are fairly different not only in amplitude but also in phase.

The Eq-time changes of T-functions statistically detected in these studies were very, very small, amounting even in the extreme case to 0.01, generally to 0.005. These correspond to about 1% or a little more against their absolute values of the real T-functions, while the individual Eq-precursor changes estimated in Part I or others were far greater than the above statistical ones, amounting to 0.05 to 0.10 in many cases, although they were not always identified for all of remarkable Eq's. Consequently, it should be considered that individual time changes of T-functions contain in many cases considerably large noise components such as the K-activity dependences, some error components and others. Besides as reasons for the above great differences in amplitude, it should be noted that there is a great smoothing effect in the statistical feature due to the five-term running mean, which corresponds to a half month mean, and that there may be a great variety in amplitude, phase and duration of individual precursor changes even for Eq's with similar magnitudes and epicenters. In fact, various types of Eq-precursor changes occurring in individual events were reported in Part I.

From the present studies, it has been made considerably clear that the time changes of T-functions at Kakioka are related to neighbouring Eq-occurrences. However, there still remain many questions or uncertainties about not only their detailed behaviour but also their actual existence itself in some cases. Many more studies on the present subject should be accumulated dealing with far numbers of data on a statistical basis as well as on an individual basis.

Meanwhile, it was pointed out in Part I that there were some K-activity dependences in time change of T-functions as one of the origins other than the Eq-precursor effect. In addition to these effects, certain kinds of periodic changes related to other unknown origins are suggested in this paper, especially in the L. P. band. The most predominant periodicity of such periodic changes seems to be about 27–29 days. These are partly related to similar periodic changes of the K-activity and/or some Eq-occurrences, but not all of them seem to be explainable by the above two effects. This interesting problem will be analyzed in detail in Part III of the present paper.

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地震発生に関連した変換函数の時間的変化（II）

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前回の報告（Part I）で，柿岡地磁気観測所の KASMMER システム毎分値データを用いた地磁気 CA 変換函数の解析法について述べ，Mar. 1977〜Dec. 1978 の資料について主として柿岡周辺の地震発生に関連した変換函数の時間的変化の予備的な解析結果を報告した．引き続き本報告（Part II）では，このような地震前兆現象的な変換函数の変化を再確認するために，同資料について詳細な統計的解析を行った結果を報告する．

今回の解析は，関連する地震についてその発生領域を2，3の小領域に分割し，各小領域からある基準以上の顕著地震 M=4.0〜6.0 を12〜18個それぞれ選定し，それらの地震に対して前回と同様の重ね合わせ統計法により，変換函数の地震前兆的変化を検出しようとするものである．また，このような震源域の分割により，各震源域における地震前兆的変化の差異についても究明しようとするものである．今回のこのような解析により，各領域における地震の前兆現象的な変換函数の時間変化がより明確に導き出され，前回の結論を十分に裏付ける結果がえられた．これらの地震前兆現象的変化は短周期帯（10，20，30，および60分周期成分）でより顕著であり，ごく常識的な地震が柿岡に近く，規模が大きければ，柿岡の地震前兆的変化は大きいらしいこともある程度確認された．統計的に検出された変換函数変化の振幅は高々0.01であり，非常に小さいが，それらはかなり高い有意性を持つものである．

更に今回は，筆者の方法とは別のパワー・スペクトル解法による変換函数（周期=20，30，60分のみ）の資料（白木，1977）について，同様の解析を行い筆者の結果と比較してみた．両者は概略において一致した結果を示しており，この点からも柿岡における変換函数の地震前兆的変化は間違いのない事実として確認された．

このような地震前兆的変化の他に，また前回も指摘した地磁気活動度依存性とも別の27〜29日周期性を持った変換函数の変化が，特に長周期帯（90，120および180分周期成分）に存在するらしいことが，今回の新しい事実として示唆される．なお，変換函数の時間変化に関連する地磁気活動度依存性については，今回も解析を行ったが，重ね合わせ統計平均的には前述の地震前兆的変化または上述の周期的変化より少なくとも小さいことがわかった．

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