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GEOMAGNETIC VARIATION ANOMALY IN THE VICINITY OF TOTTORI, FACING THE JAPAN SEA, IN THE SOUTH-WESTERN JAPAN

By

Norihiko SUMITOMO

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Abstract

Observations of three components of geomagnetic variations were recently carried out by means of two flux-gate magnetometers in coastal areas of the Japan Sea in the South-western Japan. ΔZ in short-period geomagnetic variations is negative or upward when ΔH points to the north, while ΔZ is positive or downward at observatories along the Pacific coast of the Central Japan.

$\Delta Z/\Delta H$ ratio follows to the period-dependency, amounting to -0.6 or more in short period at stations near the coast, and also to the dependency on the distance from the coast. Parkinson vectors at every station tend to point to the direction almost perpendicular to the coast line.

In order to explain these facts, the influence of the undulation of conducting layer beneath the Japan islands and that of electric currents flowing in the Japan Sea (so-called the "coastal effect") are examined and discussed in the present article. Considering the period-dependency of $\Delta Z/\Delta H$, it may be concluded that the influence of currents in the sea is rather more important than that of the undulation of conducting layer as far as the coastal areas of the Japan Sea in the South-western Japan is concerned.

1. Introduction

In recent years, an investigation on anomalies of geomagnetic variations has actively been made to get a useful information relating to a structure of the Earth's interior. The information is related to the particular distrubution of electric conductivities within the crust and the upper mantle. Conductivity depends mainly on materials and also on thermal structures within the earth. This information has, therefore, a close relation to other geophysical informations, especially to the anomaly of heat flow and also to the velocity and its attenuation for P-wave, and affords an important clue for the study of structures of the Earth's interior.

Transient geomagnetic variations originate in general firstly from sources outside the solid earth, and secondly from the currents induced within the earth. Therefore geomagnetic variations observed at the earth's surface include both inducing and induced parts. The latter is much affected by the particular distribution of electric conductivity in the earth's crust or the upper mantle. Taking into account relevant assumptions and suitable methods in analysis for separating those variations merely due to the induced fields, one can get information on the particular distribution of conductivities within the earth.

The vertical component of geomagnetic variations is most affected by the induced field. It has long been remarked that ΔZ (change in the vertical field) at the time of SSC or bays was anomalously large in the areas of the Central Japan. Since Rikitake et al. [*1953*] suggested that such anomalous behavior of ΔZ was closely related to the conductivity anomaly beneath the Central Japan, many studies and observations of geomagnetic variations have been made in various regions of Japan. Among them, the study by Rikitake and Yokoyama [*1955*] that the vectors of short-period variations tend to lie on a plane, which is called the "preferred plane" by Parkinson [*1959*], is especially excellent. It introduced a powerful technique for the study of conductivity anomaly. As the results of such intensive studies and observations, the Central Japan anomaly (Rikitake [*1959*]) and the North-eastern Japan anomaly (Kato [*1968*]) were found. Various anomalies of conductivity were also found in many other countries, including Australia, Canada, Italy, North Germany, the west coast of South America, U. S. A. and the far east of U. S. S. R.. On the other hand, it has recently been taken into consideration, as summarized by Porath and Dziewonski [*1971*], that some conductivity anomalies are not necessarily derived from the undulation of high conducting layer, but are caused by currents induced in an ocean and/or currents concentrated in sedimentary layer or nallow channels.

The distribution of $\Delta Z/\Delta H$ value when the geomagnetic field changes in the north direction is shown in Fig. 1, which is drawn by Rikitake [*1969*] on the basis

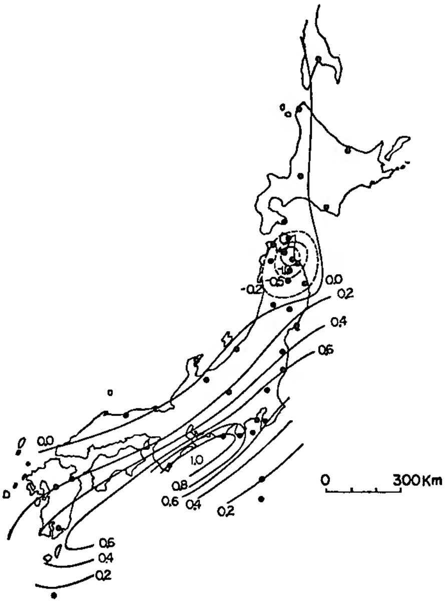


Fig. 1. $\Delta Z/\Delta H$ value distribution over the Japan for geomagnetic bays and similar changes (after Rikitake).

of data available in Japan. It reveals well the Central Japan anomaly and also the North-eastern Japan anomaly. As for the seaside part of the Japan Sea in the South-western Japan, it is not clear what a distribution of $\Delta Z/\Delta H$ is presented because of few station available. To make clear this point is one of purposes of these observations.

Miyakoshi [*1969*] reported that the sign of $\Delta Z/\Delta H$ in the short-period magnetic variations was negative, namely the Z trace was reverse to the H one, at Tottori, located near the coast of the Japan Sea in the South-western Japan, and the ratio of $\Delta Z/\Delta H$ tended to indicate the period-dependency of gemagnetic variations. It is also the purpose of the present work to examine the regional features of $\Delta Z/\Delta H$ at another areas facing the Japan Sea in the South-western Japan and also to investigate whether these features arise from the undulation of conducting layer beneath the Japan islands or are due to the currents flowing in the Japan Sea.

2. Observations and Results

Observations of three components of geomagnetic variations have been carried out at several stations in the vicinity of Tottori by means of two flux-gate magnetometers during the period from December *1969* to August *1971*. Speaking in detail, continuous observation was made at the Tottori Micro-Earthquake Observatory (*TO*), situated about *2* km apart from the coast of the Japan Sea, while simultaneous observation was successively conducted at four inland points, namely, Sakyu (*SA*), Funaoka (*FU*), Chizu (*CH*) and Tsuyama (*TS*), located in the direction making almost right angle with the coast line. Each observation at those stations was made over the period of one month or more. Sensitivities of magnetometers used were about *2 gamma/mm* on the recording chart for H and D components, and *1 gamma/mm* for Z component. The chart speed was *2.5 cm/hour*. Location of the observation stations and examples of typical magnetograms obtained at the *TO*, *FU* and *TS* stations are shown in Fig. 2. As can easily be seen from Fig. 2, Z traces at every station are negative or upward when the H variation pionts to the north, but on the contrary, the Z component is used to be in-phase with the H component for the observatories along the Pacific coast of the Central Japan. In spite of being about *50 km* apart from the coast, the *TS* station shows the similar tendency to the *TO* station. Other features at every station are that the shape of Z is similar to that of H, though sense of Z is opposite to H, but not to that of D, and also that the phase of Z is slightly in advance of H.

In order to investigate the detailed features of short-period geomagnetic variations, relations between $\Delta Z/\Delta H$ and duration times of the geomagnetic variations are examined statistically. They are shown in Fig. 3. Events used here are those having the period-range from about *5* to *90* minutes such as sudden storm commencements, bays and short-period fluctuations in the duration of magnetic storms. ΔZ and ΔH are defined as the deviation from a straight line connecting the beginning

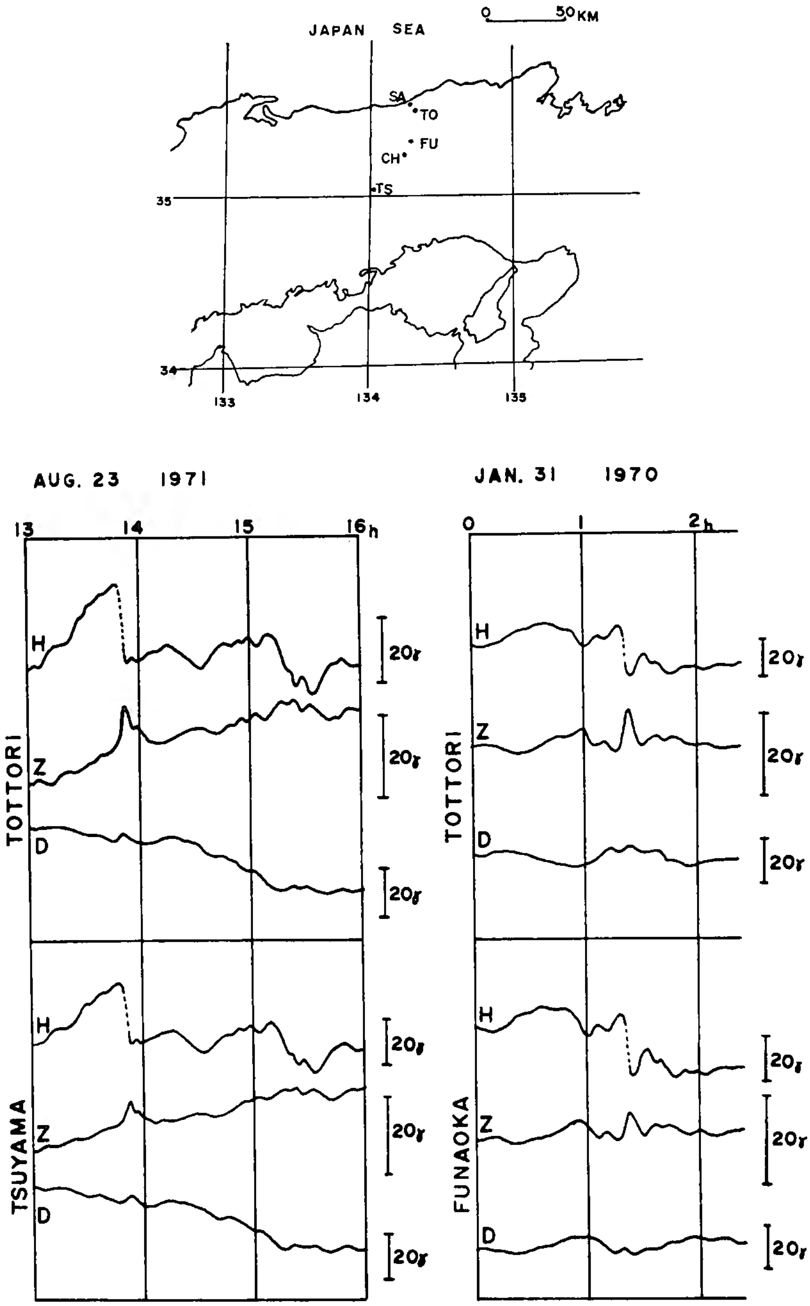
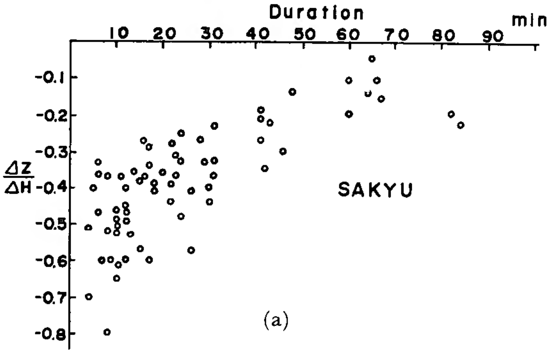
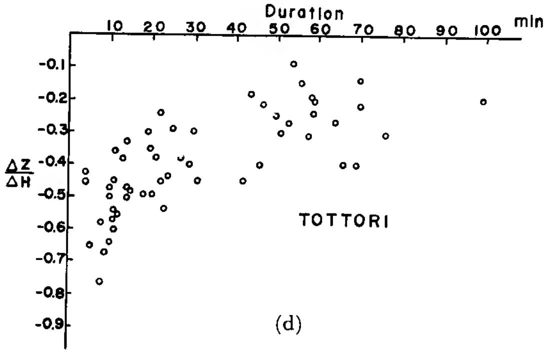


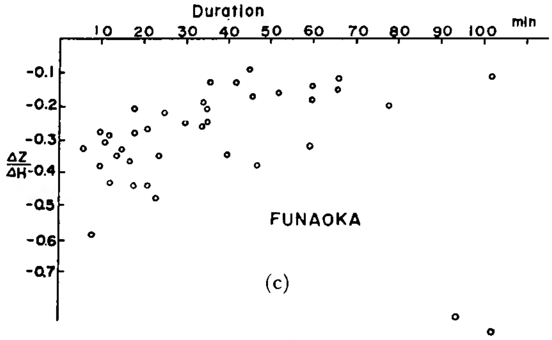
Fig. 2. Location of observation points and examples of typical magnetograms obtained at *TO*, *FU* and *TS* stations.


Duration
min
10 20 30 40 50 60 70 80 90
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
ΔZ/ΔH
SAKYU

(a)


Duration
min
10 20 30 40 50 60 70 80 90 100
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
ΔZ/ΔH
TOTTORI

(d)


Duration
min
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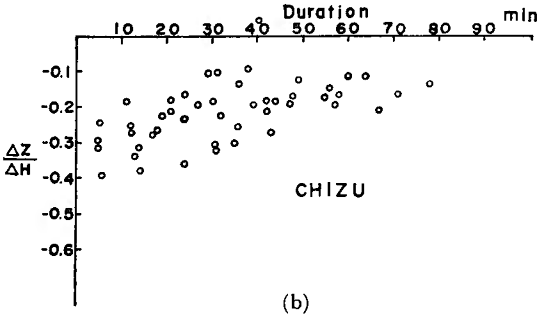
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
ΔZ/ΔH
FUNAOKA

(c)


Duration
min
10 20 30 40 50 60 70 80 90
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
ΔZ/ΔH
CHIZU

(b)

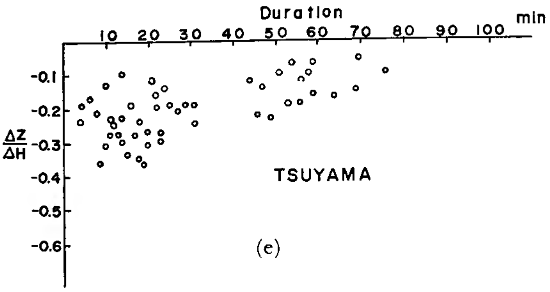


Fig. 3. Relation between $\Delta Z/\Delta H$ and duration time at *SA* (Fig. 3a), *TO* (Fig. 3b), *FU* (Fig. 3c), *CH* (Fig. 3d) and *TS* (Fig. 3e) stations.

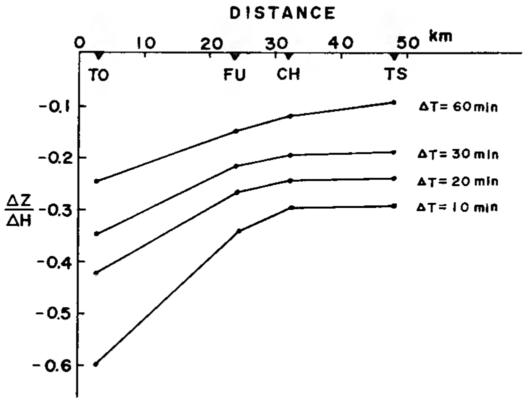


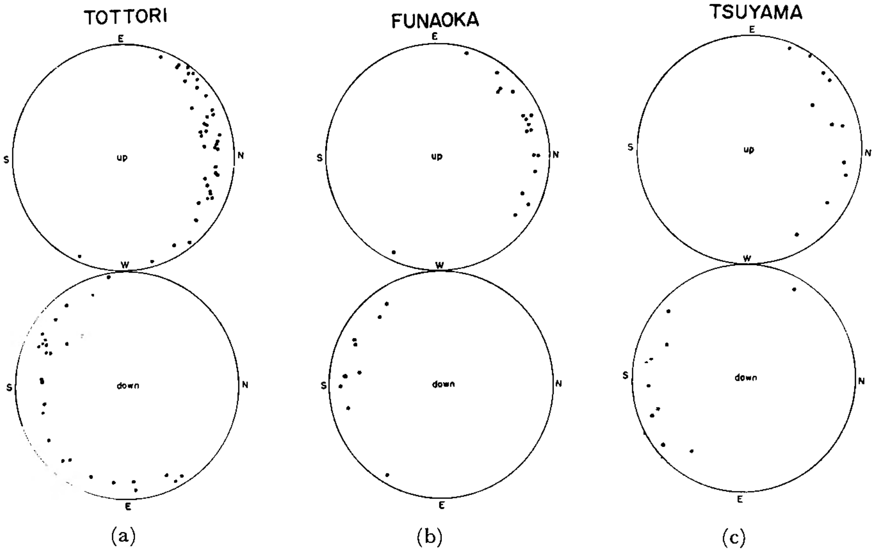
Fig. 4. Relation between $\Delta Z/\Delta H$ and distance from the coast for different duration times.

of an event with its end on the magnetogram. The duration means the time interval from the beginning of an event to its end.

It may likely be seen that $\Delta Z/\Delta H$ at every station shows a tendency of the period-dependent behavior of geomagnetic variations. Especially, it is noteworthy that $|\Delta Z/\Delta H|$ at both *TO* and *SA* stations, being situated near the coast, increases exponentially as the duration becomes shorter, amounting to *—0.6* or more.

Change of $\Delta Z/\Delta H$ versus the distance from the coast for various durations is deduced from the Fig. 3 in order to examine how $\Delta Z/\Delta H$ changes by the distance from the coast, and its result is shown in Fig. 4. It can be seen likely that the shorter the duration is, the smaller the attenuation of $\Delta Z/\Delta H$ by the distance is.

According to the method of Parkinson [*1959*], polar diagrams of variation vectors are made for every station and some of them are shown in Fig. 5. As can easily be seen from Fig. 5, it seems likely that variation vectors lie on a preferred plane for every station. Parkinson vectors (or Parkinson arrows) can graphically be obtained by using the polar diagrams. They are shown in Fig. 6. The direction of the arrow indicates the direction of maximum slope upward of the preferred plane, and the



(a) (b) (c)

Fig. 5. Polar diagram showing directions of change vectors at *TO* (Fig. 5a), *FU* (Fig. 5b) and *TS* (Fig. 5c) stations.

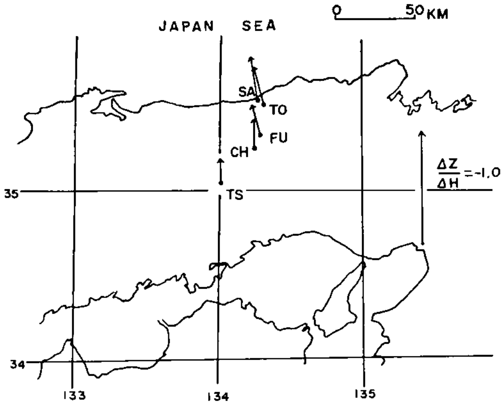


Fig. 6. Parkinson vectors for the observation stations.

length of the arrow indicates the ratio of the vertical to the horizontal variation; namely, the dip of the preferred plane. Since $\Delta Z/\Delta H$ shows the period-dependency, the Parkinson vector shows a similar tendency, too. Parkinson vectors obtained here are thought to be averaged ones as events having various durations are used. Parkinson vectors at every station tend to point to an almost north direction perpendicular to the coast line. The preferred diection dips towards the inland side from the Japan Sea. The dip angle of it is fairly larger than the angle expected. In spite of being *50 km* apart from the coast, the dip angle of the preferred plane at the *TS* station shows a similar value to the angles obtained at the stations near the coast, though the former is slightly smaller than the latter.

3. Consideration and Conclusion

Results of the observations described above are briefly summarized in the following;

1. $\Delta Z/\Delta H$ is negative at every station, the absolute value of which shows the period-dependency and especially, increases exponentially as the period becomes shorter at stations near the coast.

2. In the case of the variations having the same duration time, the nearer the station is to the coast, the larger the ratio of $\Delta Z/\Delta H$ is.

3. Parkinson vectors at every station tend to point to an almost north direction perpendicular to the coast line.

There are following two considerations to account for the facts as mentioned above. One is that these facts are reflection of an undulation of mantle conducting layer beneath the Japan islands as interpreted by Rikitake [*1969*]. The other is that they are caused by the influence of electric currents induced in the Japan Sea, which is often called the "coastal effect". Using the distribution of $\Delta Z/\Delta H$ in Japan as shown in Fig. 1, Rikitake calculated the depth of mantle conducting layer beneath the Japan islands by assuming a step model of perfect conductor. Fig. 7 shows a profile of such depth of conducting layer passing through the *TO* station in the north-south direction, which is obtained from the map of contours for the depth of conducting layer drawn by Rikitake. He took into consideration the high heat flow in the Japan Sea, so that the depth of the conductor under the Japan Sea was assumed to be *40 km*. Assuming that an inducing field changed to an almost north direction, the induced currents flows from east to west in the conducting layer, so that magnetic lines of force distort as the broken lines briefly shown in the Fig. 7. Therefore ΔZ becomes negative or upward while ΔH points to the north in the Japan Sea side. Seeing the uplift of the conductor in the Japan Sea, it can be explained that $|\Delta Z/\Delta H|$ for near-shore stations is larger than that for inland stations. However this consideration can not sufficiently explain the period-dependency of $|\Delta Z/\Delta H|$, though

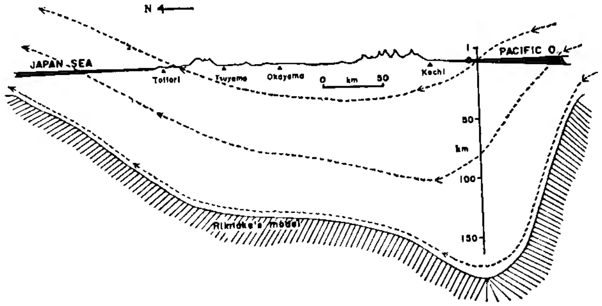


Fig. 7. Model of the depth of conducting layer beneath the Japan islands, being introduced by Rikitake, in the *N–S* profile traversing the Southwestern Japan. Broken lines indicate schematical magnetic lines of force produced by the currents flowing in the conducting layer.

some possibility accounting for it will be expected by introducing the conductivity change with depth in place of perfect conductor.

Let us examine, next, the influence of electric currents flowing in the sea. Rikitake and Sasai [*1969*] calculated the magnetic field due to the currents induced in the ocean around the Japan islands on the basis of the induction theory of non-uniform thin conductor. According to their calculation, it became clear that the influence of currents on the land was not large enough to account for the anomalous behavior of Z component, though a fairly strong Z component was, on the surface of the Japan Sea, produced due to currents induced in the sea. Therefore one must expect more currents in the sea in order to account for the behavior of ΔZ in the vicinity of Tottori by influence of currents flowing in the Japan Sea.

A recently reconsidered redistribution of current systems induced in both the oceans and conducting regions of the upper crust has been summarized by Porath and Dziewonski [*1971*]. Among various conductivity anomalies found in the world, for instance the North German anomaly and the Alert anomaly in the Canadian Arctic may be interpreted by concentration and channeling of currents induced elsewhere. In the case of the Japan Sea, the induced currents may be weak as its dimensions and depth is comparatively small and shallow, but the concentration of the currents induced elsewhere may be considerable.

Assuming that conduction currents induced elsewhere flow into the Japan Sea, the density of currents in the Japan Sea may be higher than that of currents induced only in the Japan Sea. As the density of induced currents near the surface depends on the period of inducing field variation, the density of conducting currents may also depend on the period. It may therefore be explained by the influences of conducting currents as well as induced ones in the Japan Sea that $|\Delta Z/\Delta H|$ tend to depend upon the period of events.

Let us calculate approximately the magnetic fields produced by the currents in the Japan Sea according to the Biot-Savart's law. A profile model of the depth in the Japan Sea along the north-south line passing through the *TO* station is roughly assumed as shown in Fig. 8. Taking into consideration of existence for sedimentary layer in the Japan Sea, the effective depth may be deeper than the model. Currents are also assumed to flow two-dimensionally in a conducting sea which extends to infinity in the east-west direction, because the coast line in Tottori is regarded as almost straight to that direction. Having no information about the current density,

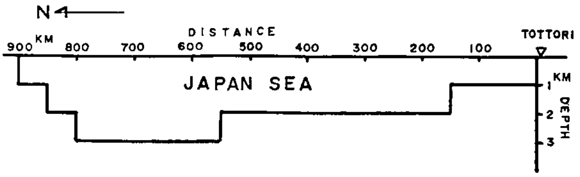


Fig. 8. Model of the sea depth in the *N*–*S* profile traversing the Japan Sea in the South-western Japan.

calculation is made by assuming the mean density in the sea to be arbitrarily I (Amp/m^2).

Intensity of magnetic fields versus the distance from the coast is shown in Fig. 9.

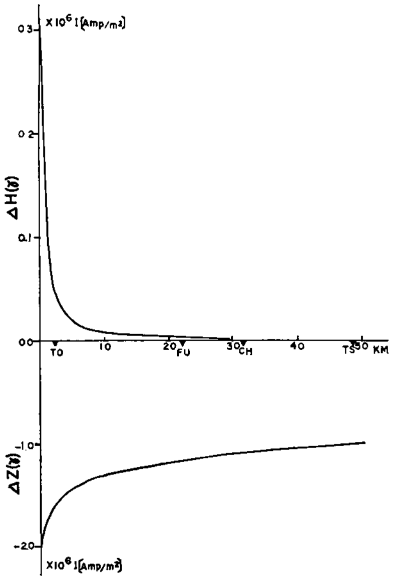


Fig. 9. Numerical calculation for attenuation of the magnetic field (in gamma) with distance produced by the currents flowing in the Japan Sea. Vertical scale is expressed in terms of a parameter of current density I (Amp/m^2).

It is evident from the figure that the vertical component does not attenuate readily even at the distance of *50 km* from the coast, while the horizontal one attenuates immediately to remarkable degree. From this fact, it may be noted that the behavior of the vertical component is not necessarily similar to that of the horizontal one, the direction of which is perpendicular to the coast, as far as the influence of the current flowing in the ocean is concerned.

Comparing Fig. 9 with Fig. 4, the curve for the duration of *10 minutes* in Fig. 4 is, for instance, in good agreement with the curve of ΔZ shown in Fig. 9. So assuming that the horizontal component is not greatly affected by the currents in the sea and is approximately equivalent at everywhere, but that the vertical one is derived from the influence of currents only, it can then be said that the change of $\Delta Z/\Delta H$ depending upon the distance from the coast may be explained by the influence of currents flowing in the Japan Sea.

The density of currents in the sea is roughly estimated by using the above model for trial. Assuming $10\,\gamma$ variation in the vertical component at the *TO* station, which is regarded as the variation due to only the currents in the sea, the mean density of currents in the sea is calculated to be about $6\times 10^{-6}\ Amp/m^2$. Then about $7\,\gamma$

variation in the vertical component due to those currents at the *TS* station, being *50 km* apart from the coast, will be observed. Since there is unfortunately no available data on the density of currents observed directly in the sea, it can not be said whether this value is valid or not. Ohchi and Yanagihara [*1969*] reported that the density of currents in the sedimentary layer in the Kanto plains was estimated to be the order of 10^{-6} Amp/m^2 through their observations of the magnetic forces and the earth surface currents. Hence, the author thinks the value of the density of currents in the sea above calculated to be fairly reasonable.

Concerning the geomagnetic *Sq* daily variation at the *TO* station, it can be said that the behavior of *H* and *D* are in good agreement with those at the Kakioka Magnetic Observatory but behavior of *Z* at the *TO* station is remarkable different in its phase and amplitude. The phase of *Z* at the *TO* station is about one hour or more later than that of *H*. Such a tendency is fairly common in coastal regions of the Japan Sea (*Tazima* [*1959*]). The author considers that this may also be attributed to the influence of currents in the Japan Sea.

Judging from the consideration mentioned above, it may be concluded that most characteristics of $\Delta Z/\Delta H$ observed in the vicinity of Tottori can be explained by the influence of currents flowing in the Japan Sea. However the influence of undulation of the conducting layer beneath the Japan islands must still be taken into consideration. It appears to the author that both effects play an important role on the interpretation of characteristics of $\Delta Z/\Delta H$ in coastal regions of the Japan Sea in the Southwestern Japan. In order to separate both effects as clearly as possible, the method of a spectral analysis or a transfer function and other powerful techniques may be introduced to the data in the near future.

Appendix

In order to examine the influence of currents flowing in the Seto-inland Sea, an observation of geomagnetic variations was temporarily made by using the flux-gate magnetometer at Marugame, facing the Seto-inland Sea, in the northern part of Shikoku island in July *1972*. Though the observed point was located only about *1 km* apart from the coast, no evidence could be obtained to show any influence of currents flowing in the sea. This may be attributed to the shallow depth, maybe being less than *100 meters*, of the Seto-inland Sea.

ΔZ was generally in phase with ΔH for the duration time of more than *30 minutes*. For that case, $\Delta Z/\Delta H$ took on a value about *0.2* and less. This value seemed consistent with values obtained already on the Pacific coast of Japan. In the case of short-period variations, ΔZ showed almost no change.

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References

Ohchi, K. & K. Yanagihara, *1969*; Island effect on the earth surface current and geomagnetic total intensity, Proc. Conductivity Anomaly Symp. Japan, *175–178* (in Japanese).

Kato, Y., *1968*; Northeastern Japan anomaly of the upper mantle, Proc. Conductivity Anomaly Symp. Japan, *19–31*.

Miyakoshi, J., *1969*; Characteristics of geomagnetic variation at Tottori, Proc. Conductivity Anomaly Symp. Japan, *65–71* (in Japanese).

Parkinson, W. D., *1959*; Direction of rapid geomagnetic fluctuations, Geophys. J. Roy. Astron. Soc., **2**, *1–14*.

Porath, H. & A. Dziewonski, *1971*; Crustal Resistivity Anomalies from Geomagnetic Deep-Sounding Studies, Reviews of Geophysics & Space Physics, **9**, *891–915*.

Rikitake, T., I. Yokoyama & Y. Hishiyama, *1953*; The anomalous behaviour of geomagnetic variations of short period in Japan and its relation to the subterranean structure, Bull. Earthquake Res. Inst., Tokyo Univ., **31**, *19–31, 89–100, 101–118, 119–127.*

Rikitake, T., I. Yokoyama & Y. Hishiyama, *1955*; The anomalous behaviour of geomagnetic variations of short period in Japan and its ralation to the subterranean structure (6th rept.), Bull. Earthquake Res. Inst., Tokyo Univ., **33**, *297–331*.

Rikitake, T., *1959*; The anomalous behaviour of geomagnetic variations of short period in Japan and its relation to the subterranean structure (8th rept.), Bull. Earthquake Res. Inst., Tokyo Univ., **37**, *1–11*.

Rikitake, T., *1969*; The undulation of an electrically conductive layer beneath the islands of Japan, Tectonophys., **7**, *257–264*.

Rikitake, T. & Y. Sasai, *1969*; Induced currents in the sea surrounding the Japan Islands, Proc. Conductivity Anomaly Symp. Japan, *111–116* (in Japanese).

Tazima, M., *1959*; The Geographycal Distribution of the Anomalous Geomagnetic Sq Variation, Jour. Geod. Soc. Japan, **5**, *70–78* (in Japanese).