BULLETIN OF THE EARTHQUAKE
RESEARCH INSTITUTE
Vol. 47 (1969), pp. 539-547

23. *The Anomalous Behaviour of Geomagnetic Variations of Short Period in Japan and Its Relation to the Subterranean Structure.*

The 12th report.

Effect of the sea surrounding the Japan Islands and a possible model of subcrustal structure.

By Tsuneji RIKITAKE and Yoichi SASAI,

Earthquake Research Institute.

(Read Feb. 25, 1969.—Received March 20, 1969.)

Summary

Deflection of electric currents induced in the earth's surface layer by the Japan Islands is studied. Although the currents induced in an earth model, in which only the large-scale conductivity contrast due to the distribution of continents and oceans is taken into account, are distorted by the non-conducting islands consisting of Japan, no magnetic field, which possibly accounts for the geomagnetic variation anomalies in Japan, is produced by the induced currents. It is therefore hard to explain the geomagnetic variation anomalies there only from the effect of the sea surrounding the Japan Islands.

Intensive observations of geomagnetic variation in Japan brought out that magnetic fields of short period at a near-coast station on islands and peninsulas are seriously affected by electric currents induced in the adjacent sea. Apart from such island and peninsula effects, the geomagnetic variation anomalies in Japan seem to be explained by an undulation of mantle conducting layer. If the undulation, the maximum deepening of which exceeds 200 km beneath the southern coast of Honshu Island, is interpreted in terms of that of high-temperature isotherm, agreement between the temperature distributions suggested independently from heat-flow observation and geomagnetic variation observation is remarkable.

1. Introduction

Study of geomagnetic variation anomaly in Japan has made considerable progress in recent years mostly through organized observations by members of a research group for conductivity anomaly. In addition to the well-known "Central Japan Anomaly"[1], an anomaly of opposite

1) T. RIKITAKE, *Electromagnetism and the Earth's Interior.* Elsevier Pub. Co., Amsterdam (1966).

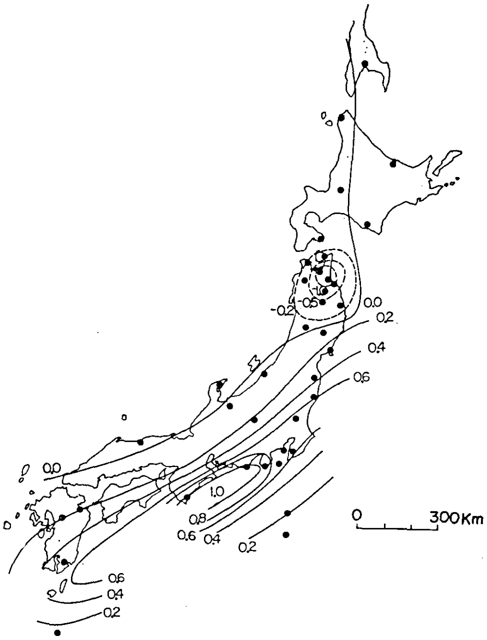

Fig. 1. The $\Delta Z/\Delta H$ value distribution for geomagnetic bays and similar changes.

sign has been found by Kato and his coworkers[2] in Northeast Japan. The area covered by the "Northeastern Japan Anomaly" is much smaller than that of the Central Japan Anomaly. Figure 1 is a schematic distribution of the ratio of the vertical field change (ΔZ) to the horizontal one (ΔH) for geomagnetic bays and similar changes.

Sasai's observation[3] on an island, about 100 km south of Tokyo, made it clear that a $\Delta Z/\Delta H$ value as high as 1.0 is observed at the southern-most station there. It was also confirmed by Sasai[4] that a very high $\Delta Z/\Delta H$, which often exceeds 1.0, is observed for rapid variations at the southern-most extremity of Kii Peninsula although such a large amplitude of ΔZ tends to decrease very rapidly towards inland. These observations led us to a conclusion that a high $\Delta Z/\Delta H$ around 1.0 or so is likely to be caused by island and peninsula effects, i.e. the anomalous field is produced by induced electric currents being concentrated in the sea along the coast-lines.

Taking such island and peninsula effects into account, the $\Delta Z/\Delta H$ distribution as shown in Fig. 1 should be somewhat modified for representing an anomaly of moderately short period. But it has been

2) Y. KATO, *Proc. Symp. Conductivity Anomaly*. Earthq. Res. Inst. (1968), 19.
3) Y. SASAI, *Bull. Earthq. Res. Inst.*, **45** (1967), 137; **46** (1968), 907.
4) Y. SASAI, *Bull. Earthq. Res. Inst.*, in preparation.

ascertained that anomalously high $\Delta Z/\Delta H$ values amounting to 0.5 or thereabouts at maximum are still prevailing over central Japan. At this point, we again encounter a question whether or not such an anomaly could be accounted for by the magnetic field produced by electric currents induced in the sea surrounding Japan. The question has been raised in the past from time to time, and Rikitake[1] repeated that it seems unlikely that the Japanese anomaly is explained by such induced currents in the sea as far as a geomagnetic variation having a duration time of 20 min. or longer is concerned.

In the first half of this paper, the writers should like to show how the induced currents in an earth model,[5),6)] for which only a large-scale surface conductivity distribution is taken into account, are deflected by the Japan Islands. It will be in such a way aimed at estimating the possible effect of the sea surrounding the Japan Islands on a geomagnetic variation which is so slow that the self-induction can approximately be ignored.

The last half of this paper is reserved for reporting very briefly on a possible subcrustal model which accounts for the geomagnetic variation anomalies in Japan for which island and peninsula effects for rapid variations are corrected. The detailed discussion about the procedure by which we arrive at the model will be published elsewhere[7)], so that only the outline of the model will be presented here.

2. Deflection of induced electric currents by the Japan Islands

A method for estimating locally induced electric currents in a non-uniform sheet has been proposed by Rikitake and applied by Sasai[3)] to an actual problem in relation to island effect. Since we are in a position to estimate induced currents of which the distribution is distorted by the Japan Islands, we may make use of a similar method.

We start from a current system induced by a sudden, step-like, magnetic change in the direction of the geomagnetic axis. The induced currents, of which the current function is denoted by Ψ_0, are estimated for an earth model for which the surface conductivity contrast of large scale and a highly conducting mantle are taken into account. The detail of the model has been described in the previous papers.[5),6)] As the surface conductivity is estimated on the basis of the sea depths read on a world bathymetric map at 15° interval in latitude and longitude, no localized irregularity of small scale such as the one represented by

5) T. Rikitake, *Bull. Earthq. Res. Inst.*, **45** (1967), 1229.
6) T. Rikitake, *Geophys. J., R. Astr. Soc.*, **15** (1968), 79.
7) T. Rikitake, *Tectonophys.*, in press.

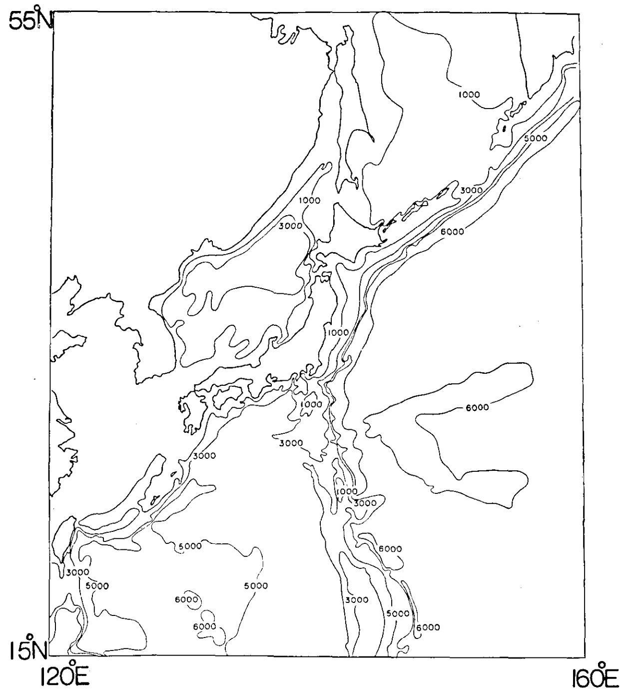

Fig. 2. Bathymetric chart surrounding Japan with 2000 m contour intervals.

the Japan Islands can be involved in the model.

Let us next consider a more detailed surface conductivity distribution around the Japan Islands. For that purpose, the sea depths in an area surrounded by meridian 120°E and 160°E and parallels 15°N and 55°N (as shown in Fig. 2) are read off from a bathymetric chart at one degree interval in latitude and longitude. The distortion of the current system, which is represented by Ψ_0 five minutes after the sudden change, due to such a conductivity distribution is then estimated by a relaxation method as described in the previous paper.[3] The current function ϕ representing the distorted portion of the induced currents is obtained as shown in Fig. 3a. The effect of self-induction is ignored in the calculation as before. A marked current vortex appears in the Japan Sea as can be seen in the figure. Figure 3b represents the distribution of the total current function, i.e. $\Psi_0+\phi$. It can be seen from the figure that the distortion of the currents caused by the Japan Islands and the adjacent area is not much except in the Japan Sea.

In Fig. 4 is shown how the total ΔZ (arising from the currents represented by Ψ_0 and ϕ and those flowing on the surface of the conducting mantle) is distributed in and around Japan. Figure 5 shows the

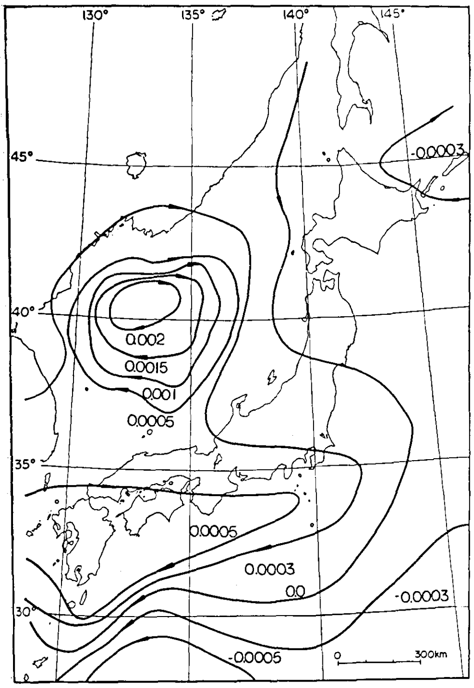

Fig. 3a. The additional current function distribution as caused by the conductivity irregularity representing Japan Islands. The unit is chosen so as to make the uniform inducing field unity.

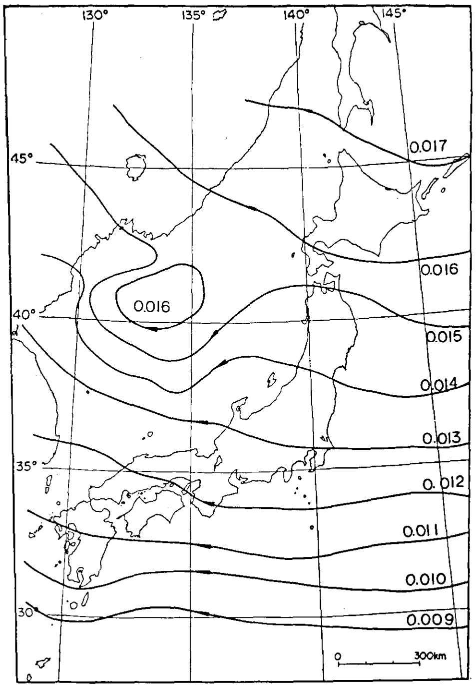

Fig. 3b. The distribution of total current function.

distribution of $\Delta Z/\Delta H$ as calculated for the inducing plus induced fields. On comparing Fig. 1 with Fig. 5, we see that the actual distribution of $\Delta Z/\Delta H$ as observed when the magnetic field changes in the north-south direction cannot be quantitatively explained only by the influence of the sea surrounding Japan. The anomalous field due to the sea effect is very much smaller than the actually observed one although there is some similarity between their distributions.

3. Undulation of mantle conducting layer beneath the Japan Islands

What the writers present in the last section proves the impossibility of accounting for the geomagnetic variation anomalies in Japan by the effect of the sea along with the various arguments[1] hitherto made. In order to explain the Central Japan Anomaly, Rikitake[1] presented what he called the "branch circuit model" which assumes a hypothetical conducting ring being connected to the high-conducting mantle in a sophisticated way underneath Japan. The model looks so artificial, as admitted by Rikitake himself, that no geophysical significance can be deduced from it. But no other way of explaining the anomaly in a

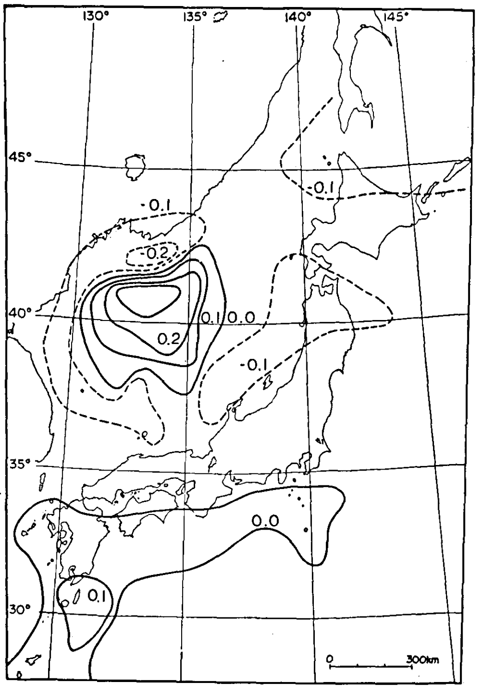

Fig. 4. The vertical field around Japan Islands in units of the inducing field.

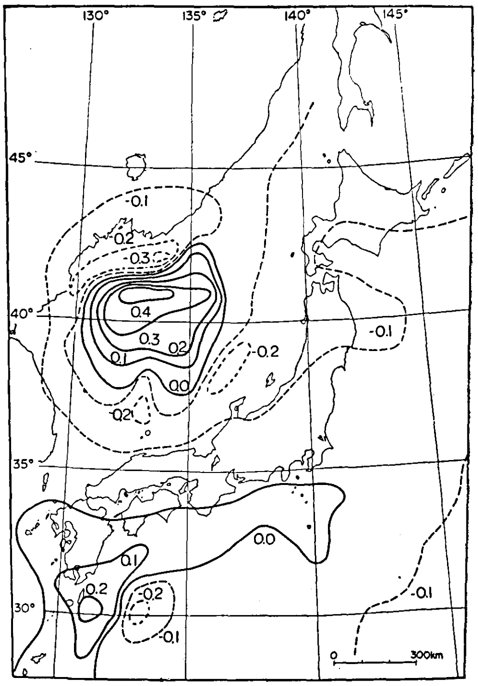

Fig. 5. The $\Delta Z/\Delta H$ value distribution as caused by the induced currents which are distorted by Japan Islands.

proper way has so far been discovered.

As pointed out in the Introduction to this paper, it becomes apparent that, when island and peninsula effects are taken into consideration, only anomalies for which $\Delta Z/\Delta H$ values amount to 0.5 or so should be dealt with as the ones arising from some agency deep in the earth. The writers are now convinced that a geomagnetic variation anomaly of that extent in amplitude could possibly be accounted for by taking undulations of underground conductor into account. Distortion of magnetic lines of force around conductors of various shapes has been studied by Rikitake.[1]

On the assumption that the geomagnetic variation anomalies in Japan are solely caused by undulations of perfect conductor, the shape of the top surface of the conducting layer is determined in such a way that $\Delta Z/\Delta H$ values are distributed as shown in Fig. 1 although the very high $\Delta Z/\Delta H$ values near coast-lines are disregarded because of the reason already stated. In south-western Japan, it is possible to rely on two-dimensional argument mainly on the basis of the north-south profiles. On the contrary, such profiles are difficult to be made use of in north-eastern Japan because the direction of geomagnetic changes is not parallel to that of the profiles of the Japan Islands. It is therefore

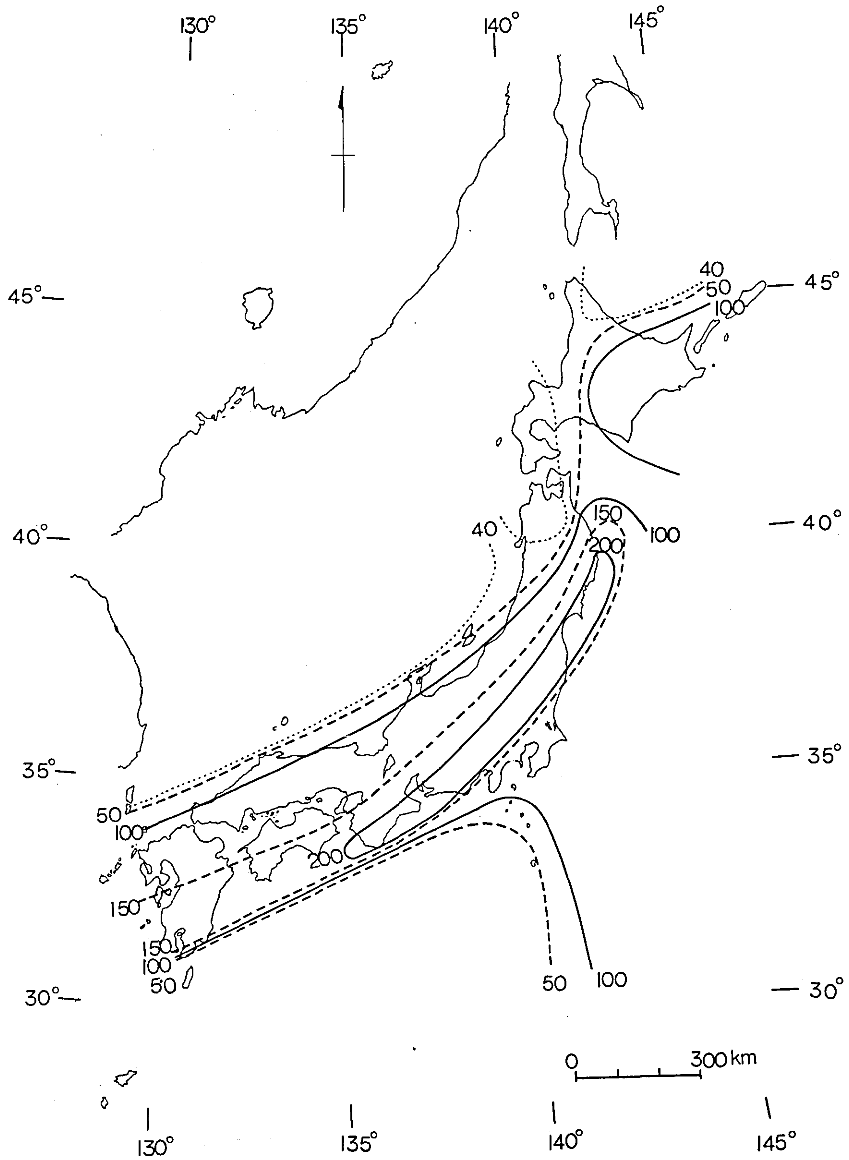

Fig. 6. Depths of mantle conducting layer in units of km underneath Japan Islands.

required to rely on the Parkinson vectors which specify the direction of underground conducting planes. At places where we have scanty geomagnetic data, it is assumed that the surface of the conducting layer coincides with the 1200°C isotherm of which the depth is estimated with a few assumptions from heat flow data in the vicinity of Japan.[8)9)]

8) S. Uyeda and V. Vacquier, *The Crust and Upper Mantle of the Pacific Area. Amer. Geophys. Un. Geophys. Monogr.* **12** (1968), 349.

9) T. Watanabe, *Proc. Symp. Conductivity Anomaly.* Earthq. Res. Inst., (1968), 167.

Figure 6 shows the depth contours of the high-conducting mantle layer thus determined beneath the Japan Islands. It is striking that the layer is as deep as 200 km beneath an area along the southern coast of Honshu Island. If the top surface of the layer is assumed to represent a high-temperature isotherm, 1200°C say, we see a marked agreement between the low-temperature mantle as deduced from the geomagnetic variation anomalies and the low heat-flow area.

4. Concluding remarks

The geomagnetic variation anomalies in Japan have not been able to be accounted for on the basis of any physically plausible model until recently. Detailed observations of the anomalies brought out, however, a way of constructing an underground model, i.e. an undulating mantle layer, which is in general compatible with heat-flow data. The model requires a deepening of the mantle conducting layer as deep as 200 km beneath the southern coast of Honshu Island. The layer must be as shallow as 50 km or so beneath the Japan Sea coast of the island where heat flow is fairly high. If such an undulation is interpreted in terms of that of high-temperature isotherm, it seems generally possible to point out that the isotherm is deep where the heat-flow values are low and shallow where the heat-flow values are high.

Systematic study of geomagnetic variation anomalies in Japan has been started by one of the writers (T. R.)[10] some twenty years ago. It is particularly important that intensive observations of geomagnetic variation as well as those of heat flow have finally led us to a physically plausible model of the upper mantle beneath the Japan Islands.

The deepening of the cold mantle beneath the Pacific coast of the Japan Islands seems to have something to do with the proposed mantle convection current[11], downward movement of lithosphere[12] and the like under an island arc. Rikitake[13] also presumed a wedge-shape penetration of non-conducting material underneath Japan from a less reliable analysis of geomagnetic solar daily variation on quiet days (S_q). It is not known whether or not such a geomagnetic variation anomaly is always accompanied by an active island arc because no dense network of geomagnetic variographs has ever been operated on an island arc except the Japan arc. It would be of geophysical importance to conduct a geomagnetic

10) T. RIKITAKE, I. YOKOYAMA and Y. HISHIYAMA, *Bull. Earthq. Res. Inst.*, **30** (1952), 207.

11) A. SUGIMURA and S. UYEDA, *Island arcs: Japan and its environs. Phys. and Chem. of the Earth*, (1969), in press.

12) B. ISACKS, J. OLIVER and L. R. SYKES, *J. Geophys. Res.*, **73** (1968), 5855.

13) T. RIKITAKE, *Bull. Earthq. Res. Inst.*, **34** (1956), 219.

variation study on island arcs such as New Zealand, Indonesia and so on.

---

23. 日本における地磁気短周期変化の異常と地下構造

第 12 報（日本列島をとりまく海洋の影響と地下構造モデル）

地震研究所 力 武 常 次
笹 井 洋 一

日本における地磁気短周期変化の異常が，日本をとりまく海洋中の誘導電流の影響で生じるのではないかという疑問は，従来しばしば論じられてきた．本報文においては，大洋や大陸を考慮した地球モデルに誘起された電流の分布が，日本列島の存在によって，どのように変形されるかを数値的に求め同時にそのつくる磁場をも求めた．この擾乱によって発生する $\Delta Z/\Delta H$ 比は実際に観測されるものと，分布においては若干の類似を示すが，振幅において非常に異なり，日本列島をとりまく海洋の影響だけで日本の地磁気短周期変化の異常を説明することは困難である．

$\Delta Z/\Delta H$ 比が 1 を越えるような場合は，例外なしに半島効果とか離島効果によって生じることが最近の観測によって示唆されているので，$\Delta Z/\Delta H$ 比が 0.5 程度の異常のみを地下の導体表面の凹凸によって説明することを試みた．その結果は Fig. 6 に示したように，本州南岸の地下に深さ 200 km に達する凹みがあることになった．この陥没は日本海に向って漸次浅くなっている．この凹凸を等温面（例えば 1200°C）のそれと解釈すれば，地殻熱流量の分布から推定される温度分布とほぼ一致するように思われる．
