BULLETIN OF THE EARTHQUAKE
RESEARCH INSTITUTE
Vol. 54 (1979), pp. 463-476

20. *Some Magnetic Anomalies Accompanied with Topographic Irregularities of Subducting Plate and Their Tectonic Implications.*

By Kazuto KODAMA,
Earthquake Research Institute

and

Osamu MATSUBAYASHI,
Geological Survey of Japan, Kawasaki, Japan.

(Received October 20, 1979)

Abstract

From the detailed aeromagnetic survey data and seismicity data on the area around the Japan arc, it was found that several magnetic anomalies with relatively short wave-lengths are accompanied with high seismic activity. Based on the results of model analysis, geological data and crustal structures inferred from seismic studies, we propose a possible interpretation that irregularities on the underthrusting plate such as seamounts or local bathymetric highs cause the magnetic anomalies, earthquakes and certain other surface geological features.

Introduction

Recently the results of detailed airborne magnetic surveys in the area around the Japan arc have been published by the GEOLOGICAL SURVEY OF JAPAN (1978). Based on these and other magnetic data obtained by the Geographical Survey Institute and the Hydrographic Office, Maritime Safety Agency of Japan, some tectonically interesting facts, such as positive magnetic lineations along the arc, have been pointed out by several workers (SEGAWA and OSHIMA, 1975; OSHIMA *et al.*, 1975; SEGAWA *et al.*, 1976).

In the following sections, we use mostly the data given by the Geological Survey of Japan (hereafter called GSJ) which were obtained by their intensive surveys for the purpose of prospecting mineral resources (GSJ, 1978). In these data we noticed that several magnetic anomalies appear to be associated with other features such as high seismic activities, gravity anomalies, and surface geological indications for structural uplifts. In this investigation we paid special attention to the local magnetic anomalies characteristically existing in the continental shelf of Japan where, generally, the magnetic field is quiet.

Data Descriptions

Detailed airborne and shipborne magnetic total force surveys in the coastal range and continental shelf of the Japan arc have revealed remarkable positive magnetic anomaly belts in the area east of Honshu to southern Hokkaido (TADA and FUJITA, 1973; OSHIMA, *et al.*, 1975), which may have a significant meaning in the development of the trench-island arc system (SEGAWA and OSHIMA, 1975; SEGAWA, *et al.*, 1976). Especially, the magnetic anomalies observed in the continental shelf off southern Hokkaido show several interesting features. Figure 1 is the contour map, presented by GSJ (1978), of the aeromagnetic total force of the area at the flight height of 1500 feet. The area covered by Fig. 1 is indicated by a frame (A) in Fig. 2. It seems to be convenient for the following discussion to divide the contoured area

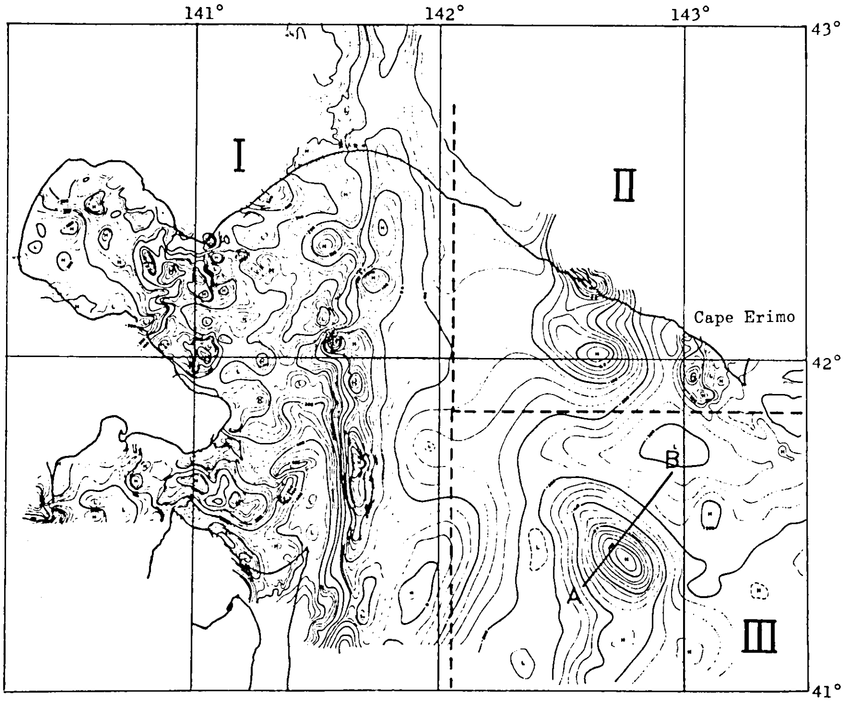

Fig. 1. Aeromagnetic total force anomalies in the continental shelf area off the coast of southern Hokkaido to northeastern Honshu (GSJ, 1978). The flight height is 1500 feet. Contour interval is 25 nanotesla (1 nanotesla=1 gamma). For the convenience of detailed discussion the whole area is divided into three regions as I, II and III. A profile along AB in region III was used for the two dimensional magnetic modelling as described in the text.

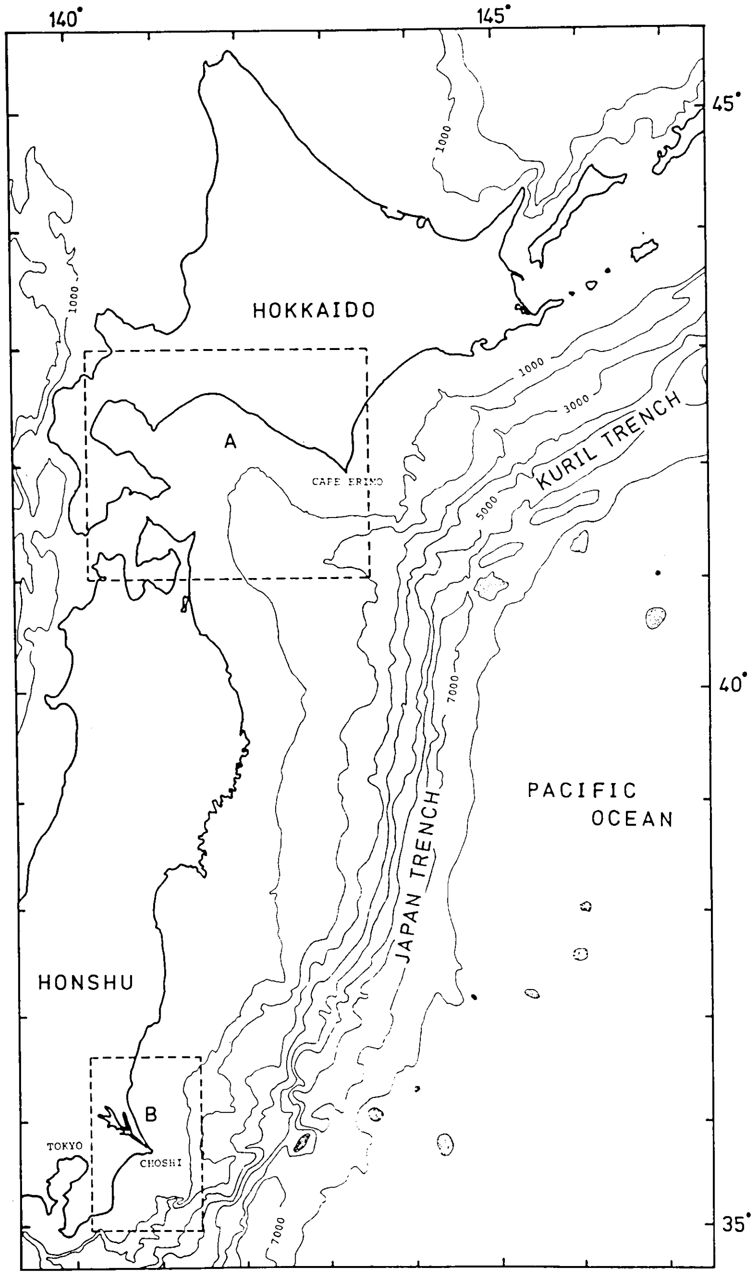

Fig. 2. Bathymetric chart off the coast of southern Hokkaido to northeastern Honshu, based on survey of the Hydrographic Office, Maritime Safety Agency of Japan (1966). Localities of seamounts are indicated by cross-hatching. Contour interval is 1000 m.

into three regions each of which seems to have its own magnetic anomaly pattern.

One is the western half of the area which is identified as region I in Fig. 1 where magnetic anomalies with short wave-lengths are prevailing. Especially, a north to south trending positive anomaly belt is notable along the longitude of 141.5°E. It has already been reported that this magnetic lineation can be traced further to the north and south (SEGAWA and OSHIMA, 1975). Interpretation of this anomaly has been made by several workers (SEGAWA and OSHIMA, 1975; OGAWA and SUYAMA, 1976; SEGAWA, *et al.*, 1976) in connection with a possible buried volcanic or metamorphic belt.

In region II, no aeromagnetic data has been obtained on land area, but two positive magnetic anomalies west of Cape Erimo are characteristic. According to OGAWA and SUYAMA (1976), the large anomaly with relatively long wave-length and the small one near Cape Erimo correspond to the ultrabasic rocks of Kamuikotan and Hidaka metamorphic belts respectively. Both these metamorphic belts are known to run in a north-south direction across central Hokkaido.

Region III of Fig. 1 as a whole shows magnetic quietness except an isolated positive magnetic anomaly southwest of Cape Erimo. The quiet magnetic pattern surrounding this local anomaly agrees well with the fact that the thick sediments of the Cretaceous to Neogen age (GSJ, 1978) are widely distributed in the gentle trough penetrating in the northwest direction from the junction of the Kurile and Japan trench as seen in Fig. 2.

As is shown in Fig. 2 there exists no local bathymetric high which might be expected to cause the isolated magnetic anomaly of region III. The relatively longer wave-length of this anomaly when compared to those of others suggests that the magnetic source may be buried more deeply than others. Figure 3 is the shallow seismicity map of the same general area (region II and III) including microearthquakes compiled by TAKANAMI (1977) for the period of 1973 to 1977. It is evident in the map that shallow earthquakes occurred frequently under the area of the positive magnetic anomaly cited earlier. On the other hand, according to the velocity structures of the area given in a north-south cross section passing through region III (ASANO, *et al.*, in preparation), the uplift of the structure with a velocity of 6.2 km/sec can be found up to about 10 km below sea level (Fig. 4). Figure 5 is the free air gravity anomaly map in and around Hokkaido (TOMODA, 1974). The negative anomaly up to −200 mgal of the offshore area can be attributed to thick sediments. However, in the area showing the positive magnetic anomaly cited earlier, it can be found that the general

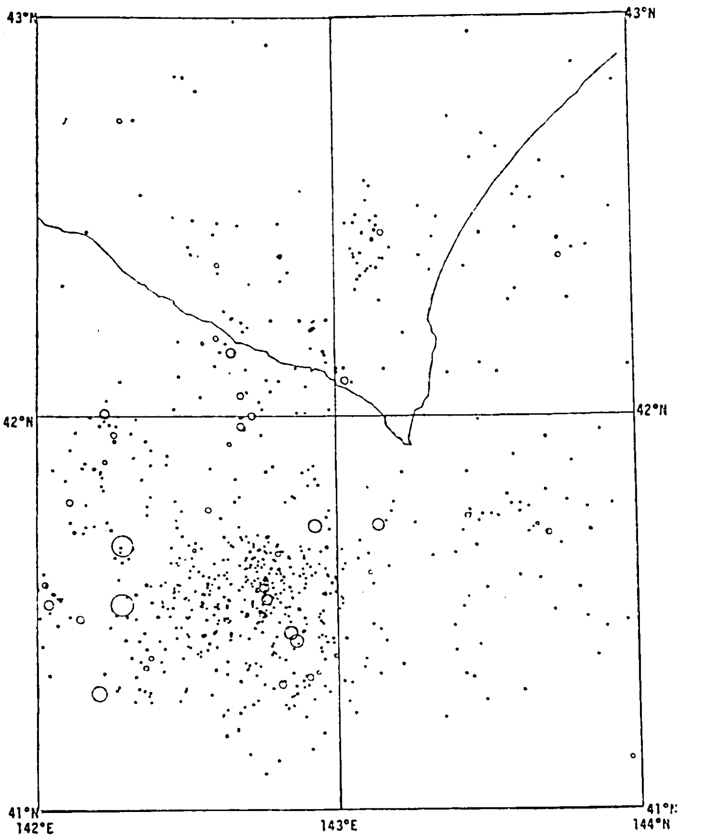

Fig. 3. Shallow seismicity (0-35 km) off the coast of southern Hokkaido for the period of April 1973, to December 1977, as compiled by TAKANAMI (1977). Note that shallow earthquakes occurred frequently in the limited area as described in the text.

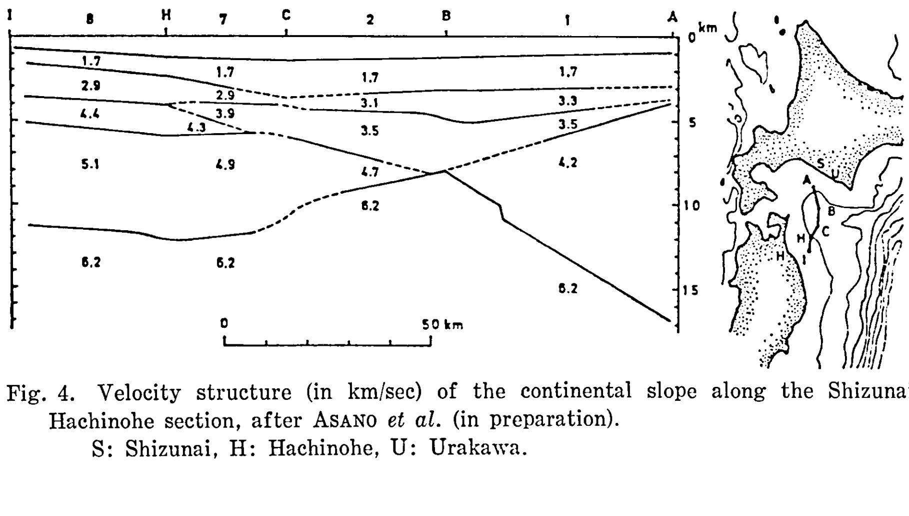

Fig. 4. Velocity structure (in km/sec) of the continental slope along the Shizunai-Hachinohe section, after ASANO *et al.* (in preparation).
S: Shizunai, H: Hachinohe, U: Urakawa.

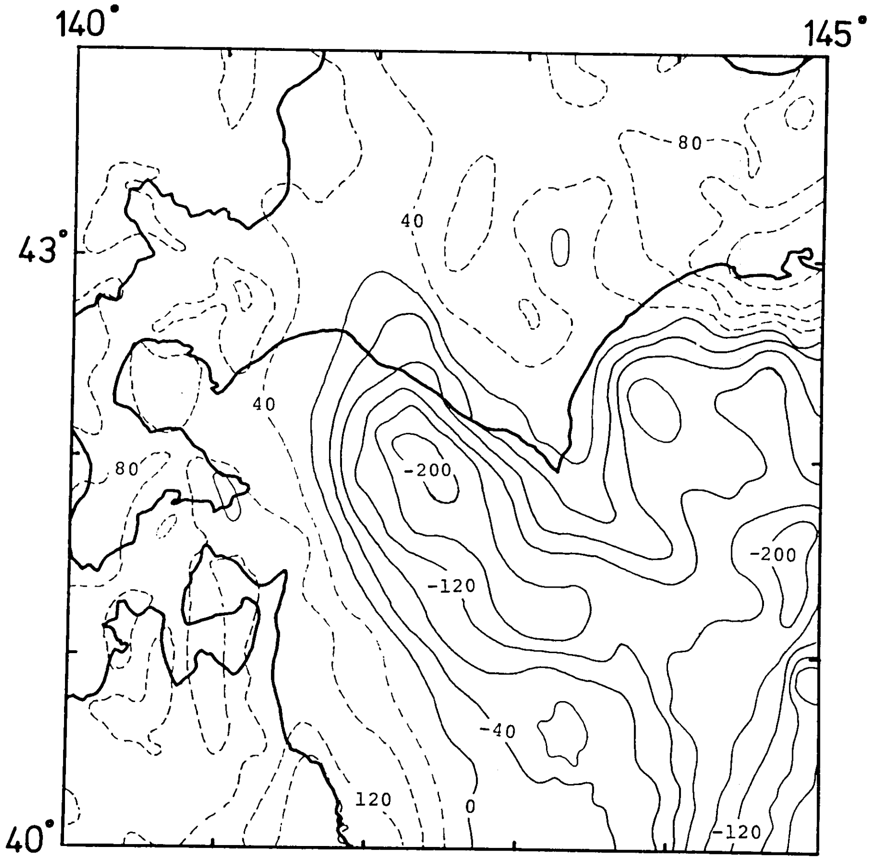

Fig. 5. Free air gravity anomaly map (in mgal) around southern Hokkaido to north-eastern Honshu, reproduced partly from TOMODA (1973).
Contour interval is 40 mgal.

negative gravity anomaly is a little disturbed implying that a positive anomaly might be overlapping the surrounding negative anomaly. These data all seem to indicate the existence of an intrusive body under the area of the magnetic high.

The local magnetic anomaly associated with earthquakes like the one just described can be found further south off the Kanto district also. Figures 6(a), (b) show the aeromagnetic anomaly derived from measurements at 1500 ft (GSJ, 1978) and the seismicity at shallow (0–40 km.) and intermediate depth (40–65 km.) of the eastern Kanto district including the offshore areas (MAKI, *et al.*, 1978). The area covered by Fig. 6(a) is indicated in Fig. 2 by frame B. Comparing both figures, correspondence of positive magnetic anomaly and dense population of earthquakes can be recognized at four areas along the eastern coast of Japan. It is notable that the positive magnetic anomaly is correlated with the occurrence of earthquakes which occurred at deeper depth when compared to the case in southern Hokkaido.

OGAWA and ISHIWADA (1976) and GSJ (1978) interpreted the aeromagnetic data of the district on the basis of the correspondence of magnetic anomalies with the distribution of Paleozoic to Tertiary formations deduced from deeply drilled cores on land and seismic reflection data in oceanic areas. According to them, the magnetic anomalies

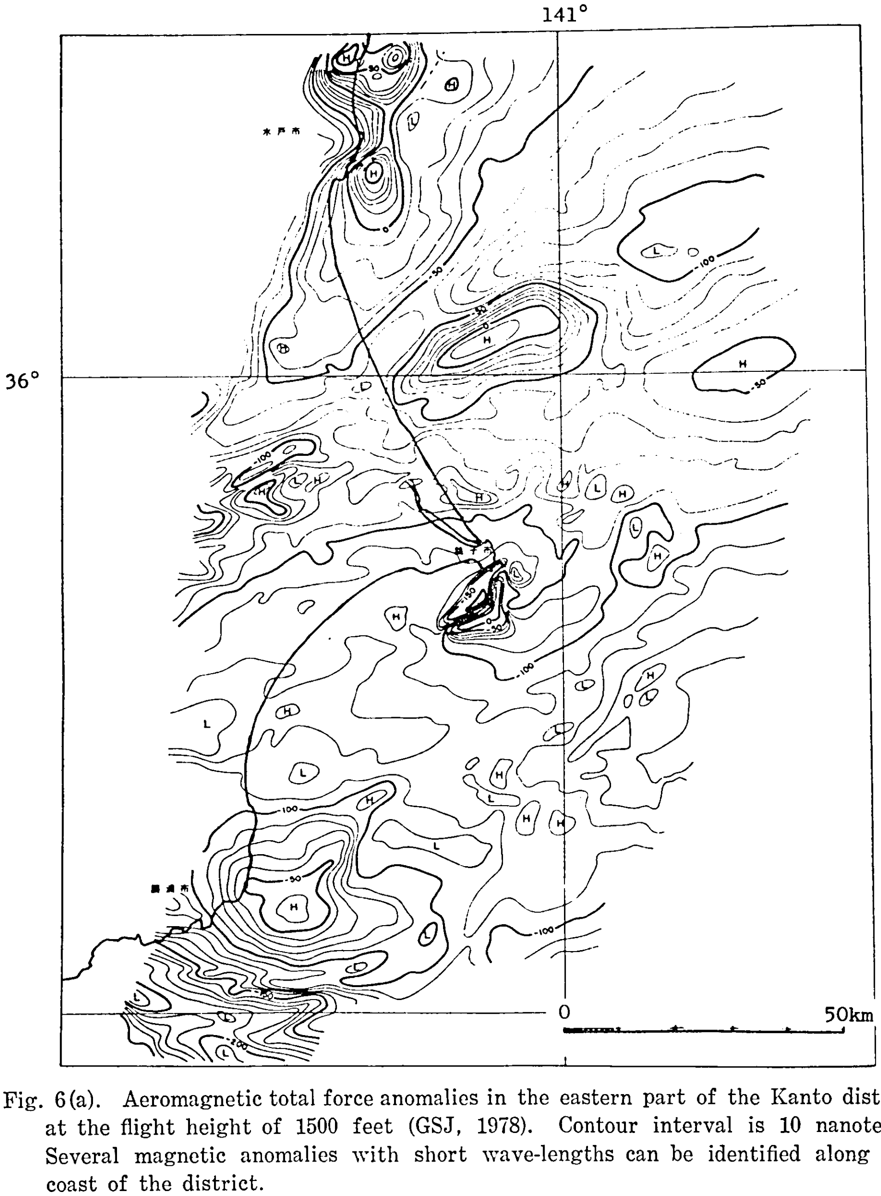

Fig. 6 (a). Aeromagnetic total force anomalies in the eastern part of the Kanto district at the flight height of 1500 feet (GSJ, 1978). Contour interval is 10 nanotesla. Several magnetic anomalies with short wave-lengths can be identified along the coast of the district.

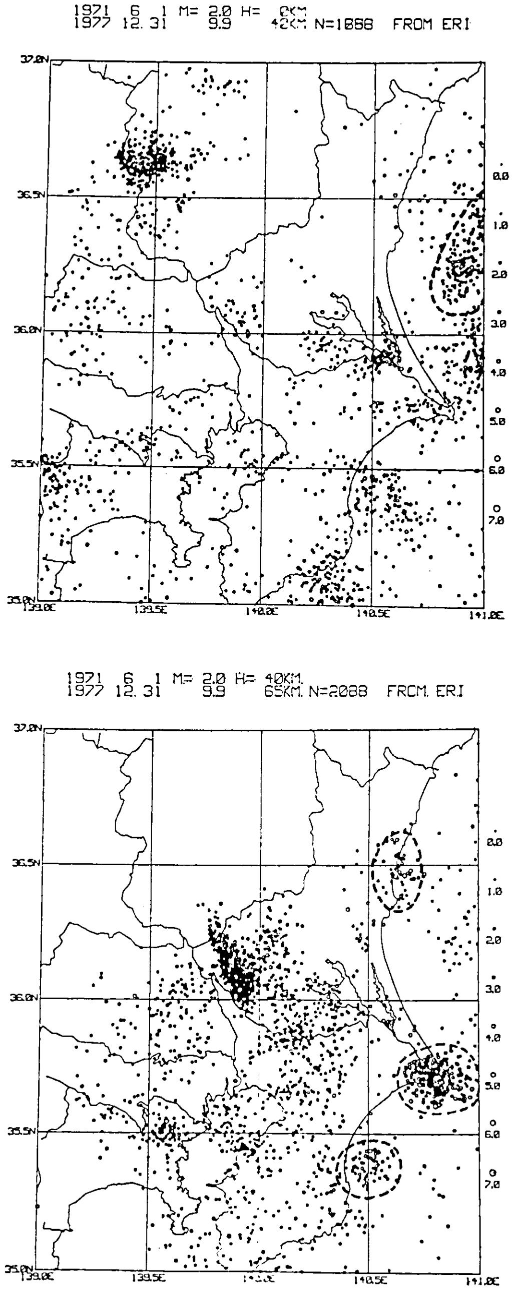

Fig. 6(b). Shallow (0-40 km, top) and intermediate depth (40-65 km, bottom) seismic activities of the area given by MAKI *et al.* (1978). All of the earthquakes ($M \geqq 2.0$) during June 1 in 1971 to December 31 in 1977 are included. Four regions indicating good agreements with magnetic anomalies in Fig. 6(a) are surrounded by dotted circles.

indicated in Fig. 6(a) can be caused by buried metamorphic rocks or uplifted basement structures possibly including basic volcanic rocks with appropriate magnetization intensity at the depth of several hundred meters to several kilometers. Although a clear discrepancy in depths is recognized between inferred magnetic sources (several kilometers at most) and hypocenters (several tens of kilometers), we believe the agreement of the locations of the magnetic anomaly and high seismicity is more than just accidental. In the following discussion, we would like to speculate on the problem from the view point of a regional tectonics.

Discussion

First, we consider the possible origin of the inferred magnetized body located off the coast of southern Hokkaido. In this case we emphasize the fact that the area exists just landward side of the junction of the Kurile and Japan trenches. This tectonic situation leads us to consider the problem in the light of Vogt's idea (VOGT, 1973), which attributes the formation of island arc cusps to the subduction of buoyant aseismic ridges. One of the most typical cases is the junction of the Kurile and Aleutian trenches, where the Emperor seamount chain is intersecting in the NNW-SSE direction. Around the cusp of the Kurile and Japan trenches, however, no aseismic ridge can be found except some scattered seamounts (Fig. 2). In our view, these seamounts may be the tailing end of an aseismic ridge or seamount chain the main part of which has already subsided under the overriding plate. This speculation leads us to suspect that the origin of the inferred magnetized body may be a part of a seamount chain which has already sunk. In order to confirm the above idea we made an effort to estimate the scale and depth of a buried magnetized body based on the aeromagnetic data of the area.

For the sake of simplicity, we made analysis with a two dimensional model assuming a uniformly magnetized body. Calculation was made so as to fit the calculated anomaly to the observed one by an iterative curve matching technique with the use of the computer graphic system developed by GSJ (OGAWA, 1977). As the observed data we adopted the NE-SW trending magnetic profile as shown in Fig. 1 by A-B. Since we can find no visible bathymetric high corresponding to the magnetic anomaly, model parameters such as the dimension, depth and magnetization vector of the inferred magnetized body were forced to be sought by trial and error. At the first stage of computation we set up a starting model by taking the wave-length and amplitude of the observed anomaly into consideration, and then tried to modify

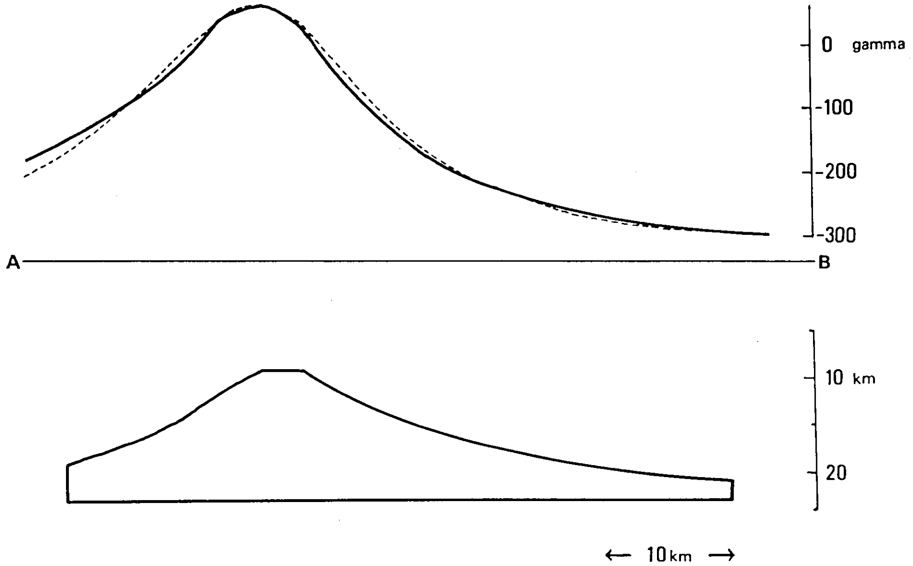

Fig. 7. The best fitting two dimensional magnetic model. The profile AB in Fig. 1 was used for the modelling.

Top: Calculated (broken curve) and observed magnetic anomalies.

Bottom: The inferred magnetized body burying under the area studied.

model parameters iteratively until the square difference between the observed and calculated anomalies became minimum. Figure 7 indicates the shape of the best model thus found, and also the observed and calculated anomalies. The model parameters are following; Inclination $=55°$, Declination$=55°$, Intensity$=3.4\times10^{-3}$ emu/cc, Top depth of the body$=10$ km (below sea level).

The depth of 10 km as inferred from our model calculation may be too shallow for a seamount sitting on the normal plate interface at a distance from the trench axis (the depth of the interface at the position would be 30 to 50 km). However, in general, the formation of a cusp should be accompanied with the excess of subsiding plate, and the excess can form an upward bending of the interface.

On the other hand, the shallow high seismicity of Fig. 3 may be interpreted by expecting that a subsided seamount would have a role in the irregularity of the interface between the continental and oceanic plates. Such an irregularity or barrier may produce stress concentration around it, which would lead to the occurrence of earthquakes. The relationship of earthquakes and barriers or obstacles on plate boundaries has been investigated by AKI (1978). Based on an interpretation of seismic data, he classified the barriers, which would initiate or stop rupture propagation, into four major categories. The concentration of earthquake occurrences of the region under present discussion and the proposed irregularity which is now assumed to be a subsided seamount would be included in the category of Aki's "brittle inhomogeneous barrier". In addition, the aftershocks of Tokachi-oki earthquake in 1968 may be taken as a possible example of the earthquakes generated by the irregularity proposed here. According to KANAMORI (1971), the main shock occurred at 143.22°E, 40.84°N at the depth of 7.1 km and was interpreted as a low angle thrust fault which is common with great earthquakes along the trenches of the northwest Pacific. The largest aftershock was a normal faulting with the slip direction opposite to that of the main shock. He explained this peculiar aftershock occurrence in terms of a coupling between the main shock and the aftershock region bounded by a trough branching off from the junction. That is, the largest aftershock was induced by a sudden displacement of the continental lithospheric block associated with the main shock

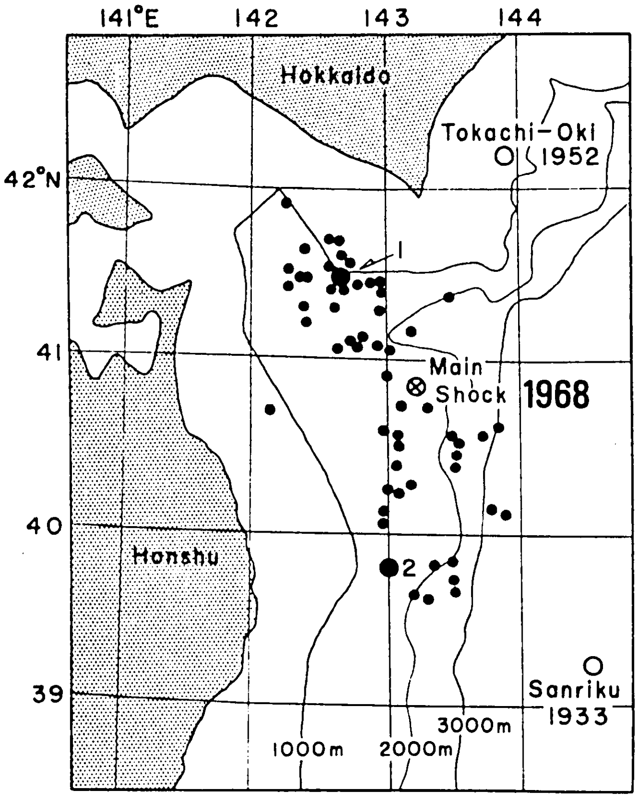

Fig. 8. Aftershocks of the Tokachi-oki earthquake within 24 hours after the main shock, from KANAMORI (1971). The map is based on the Earthquake Data Reports of USCGS and is compiled by TSUMURA (personal communication, 1970). The largest and the second-largest aftershocks are indicated by the number 1 and 2 respectively.

and this mechanical coupling was caused by the lithospheric contortion at a junction where two trenches meet. As shown in Figure 8 the aftershocks, including the largest one ($M_s=7.5$), occurred concentratedly just in the area of our magnetic anomaly. We note, moreover, that aftershocks jumped northward towards our proposed structural uplift. NAKAJIMA (1974) obtained mechanism solutions of the earthquakes before and after the main shock. He summarized that all of the mechanism solutions of earthquakes since 1964 till the time of the main shock (May 16, 1968) were quite similar to that of the main shock (thrust fault), while aftershocks showed a remarkable regionality. That is, mechanism solutions of the main shock region were thrust type and those of the largest aftershock region including our magnetic anomaly were characterized by the various solutions such as thrust, normal and strike slip faults. More interestingly, the high seismic activity still remains in the corresponding area until now, as already shown in Fig. 3. Therefore, we interpret that the larger aftershocks of Tokachi-oki earthquake, 1968, and their complicated mechanisms were due possibly to the abrupt stress concentration and complicated stress state around the barrier induced by the main shock. The persisting seismic activity would be due to the stress concentration caused by the gentle and stationary movement of the subducting Pacific plate. However, the difference in the mechanism solution and depth between the main shock and its largest aftershock still remains as a problem.

Next, let us consider the case of the area off the Kanto district where the correlation of seismicity (40-65 km depth) and magnetic anomalies can be found in four places (Figs. 6(a), (b)). However, one of them, the magnetic anomaly north of Choshi is different from the other three anomalies and coincident with the dense population of earthquakes at shallower depth (0-40 km). Judging from the wavelengths of the anomalies, the inferred magnetized bodies may exist at shallower depths than the case of southern Hokkaido. In fact, the distinct magnetic anomaly near Choshi (Fig. 6(a)) can be attributed to Paleozoic formations with volcanic ejecta outcropping locally (GSJ, 1978). Other anomalies of the area may also be due to local uplifts of the basement. As pointed out earlier, the difference in depth between the inferred magnetized bodies and hypocenters may be as much as several tens of kilometers, so that it is difficult to attribute the magnetic sources directly to the interface irregularities on the subsiding plate. In this area, upward bending of the subsiding plate, like in the case off southern Hokkaido, is less likely because the Kanto district does not face the junction. However, this discrepancy may be overcome partly by assuming that local uplifts of the basement formations causing magnetic anomalies is caused by some deeper sources on the interface of the subsiding oceanic plate. These inferred irregularities may be some seamounts which have already subsided. Several seamounts existing outside of the Japan trench east of the Kanto district suggest that there may be some seamounts already subducted (see Fig. 2).

We believe that the remaining problem is to make clear the spatial distribution of the stress and the individual nature of the barrier, because, as discussed by AKI (1978), some barriers can play a part in preventing rupture while others may initiate a rupture propagation of major earthquakes. In any case, the role of irregularity on the oceanic plate, like seamounts or local bathymetric highs, in the process of subduction, seems to be worth further investigation.

Acknowledgement

We are grateful to Drs. T. Takanami and T. Maki for kindly providing us the seismicity maps of the southern Hokkaido and Kanto districts. We also thank Professor S. Uyeda for critically reading the manuscript.

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20. 沈みこむプレート上の地形的凹凸に伴う地磁気異常とそのテクトニックな意味

地震研究所 小玉一人
地質調査所 松林修

日本列島周辺の詳細な空中磁気探査及び地震活動データから，比較的短波長の地磁気異常のいくつかが，高い地震活動を伴うことが判明した．モデル解析，地質学的データ及び地震学的に推定される地殻構造などに基づき，海山や局地的な隆起地形のような，沈みこむプレート上の凹凸が，地磁気異常，地震，表層地質の特徴などの原因をなすという解釈を提唱する．