

DIP OF SUBDUCTING OCEANIC CRUST OFF THE SANRIKU COAST, NORTHEAST JAPAN, INFERRED FROM GEOMAGNETIC ANOMALIES

By

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ABSTRACT

Aeromagnetic survey over the continental slope region off the Sanriku coast, Northeast Japan, was carried out by the Geological Survey of Japan, and the total intensity aeromagnetic map revealed that the oceanic magnetic lineation penetrates the Japan Trench. Magnetic data were analysed by a curve fitting method utilizing inclined two-dimensional model. From this analysis, the dip of the subducting oceanic crust was calculated to be approximately 15 degrees in this continental slope region. This result is compatible with previous determinations of five degrees under the Japan Trench and 30 degrees under the Northeast Japan Island Arc. Because of the structural deviation from the two-dimensional assumption, the actual dip might be somewhat lower than 15 degrees.

INTRODUCTION

Aeromagnetic survey over the area off the coast of Sanriku district, Northeast Japan, was carried out by the Geological Survey of Japan in 1980. The purpose of this survey was to obtain basic data for evaluating the possible existence and extent of hydrocarbon deposits and for clarifying the submarine crustal tectonics.

The surveyed area, as shown in *Figure 1*, extends about 100 km \times 300 km in the continental slope region. The water depth of the area ranges roughly from 1,000 m to 4,000 m. The western limit of the area is 60–80 km to the east from the Sanriku coast, and the eastern side is located about 30 km to the west of the Japan Trench axis.

The total intensity anomaly map produced from this survey is presented in *Figure 2*. It will be published by the Geological Survey of Japan (1982) at the scale of 1 : 200,000. The eastern part of this map is characterized by a very distinctive anomaly pattern consisting of ENE–WSW trending magnetic lineations. This anomaly pattern is considered to be the westward extension of the oceanic magnetic lineations across the trench and it is most probably related to the ocean floor spreading.

It was first suggested by Uyeda *et al.* (1967), and was confirmed by Oshima *et al.* (1975) that the oceanic lineation penetrates Japan Trench in this area. Also, Oshima *et al.* (1975) plotted the geomagnetic total intensity anomalies as contour maps with 50 nanotesla contour intervals. Referring to these results, the magnetic lineations which

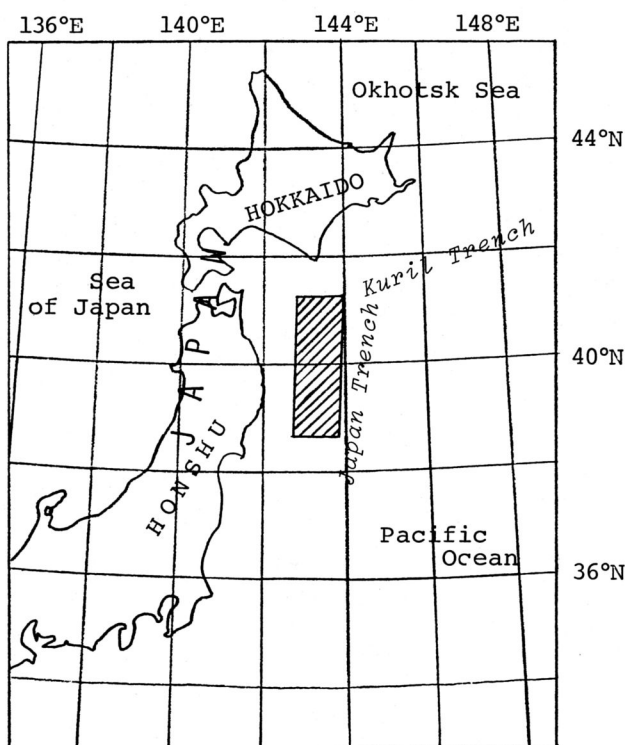


Figure 1. Location of surveyed area off the Sanriku Coast (hatched part).

are shown in *Figure 2* are identified to be generated by the oceanic crust.

As the linear pattern of the magnetic anomaly map is the surface manifestation of the subducting oceanic crust, the dip of the subducting plate under the continental slope region can be determined by analysis of the data obtained from this survey.

METHOD OF ANALYSIS

The magnetic lineations trending $N75^{\circ}E$, decreases its amplitude as the oceanic plate descends deeper under the continental crust. This type of anomaly is interpreted as a typical case of inclined two-dimensional structure. Therefore, if parallel profiles are selected arbitrarily, the geometry of the anomalous structure of one profile differs from that of the other profiles only with respect to the distance from the profile lines to the anomalous body. That is, upward or downward continuation of one profile must fit the others, if the structure is sufficiently approximated by the two-dimensional model. Actually, however, the oceanic crust is overridden by the continental crust, which may cause some magnetic anomalies. Although it is possible that such anomalies of shallower origin could distort the two-dimensional approximation to some extent, the distortion is not serious enough to affect the two-dimensional analysis, because these anomalies do not trend in any particular direction and much less in the direction of lineation.

Here we can use either upward or downward continuation, but as is well known,

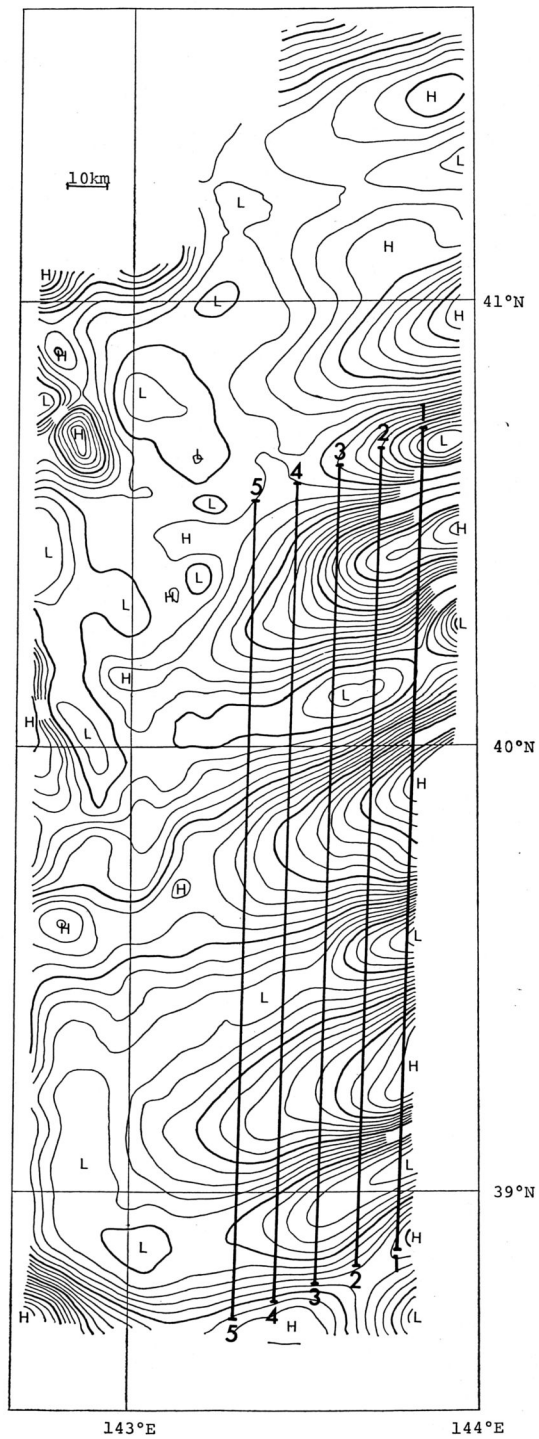


Figure 2. Total intensity aeromagnetic map of the total surveyed area. Magnetic field values are removed the International Geomagnetic Reference Field (IGRF 1975), and contoured in the interval of 10 nT. Five lines of profiles put into analysis are indicated by thick numbered lines.

downward continuation has a noisy character because of the higher sensitivity to shallower anomalous bodies. Therefore, we have analysed the magnetic profiles by a curve fitting method utilizing two-dimensional upward continuation.

The formulation of upward continuation and its application to the total intensity magnetic anomalies were discussed many years ago (Grant and West, 1965; Henderson, 1970 etc.), and the formula is given as follows. If the distribution of magnetic anomalies $F(x, y, 0)$ on the surface of base level is known, and no magnetic source exists above this level, anomaly field value $F(x, y, h)$ at the height of $h(h > 0)$ is, using cartesian coordinates, calculated by

$$F(x, y, h) = \frac{h}{2\pi} \int_{-\infty}^{+\infty} \int_{-\infty}^{+\infty} \frac{F(\alpha, \beta, 0)}{\{(x-\alpha)^2 + (y-\beta)^2 + h^2\}^{3/2}} d\alpha d\beta. \quad (1)$$

As two-dimensional structure is under consideration, it is assumed that the source structure, and accordingly magnetic anomalies are uniform in the direction of y -axis. Then, omitting the indication of y , the equation (1) can be transformed to

$$F(x, h) = \frac{h}{\pi} \int_{-\infty}^{+\infty} \frac{F(\alpha, 0)}{(x-\alpha)^2 + h^2} d\alpha. \quad (2)$$

Now select two magnetic profiles $F(x, 0)$ and $G(x, 0)$, and let $F(x, 0)$ be on the ocean-side. Then, the upward continuation of profile $F(x, 0)$ determined by equation (2) is fitted to the profile $G(x+\delta, 0)$ within some minor displacement. Here, as a measure of fitness we may use the root mean square difference $D(h, \delta)$ between two horizontal first derivatives (longitudinal gradients) of profile $G(x+\delta, 0)$ and upward continued profile $F(x, h)$, i.e.,

$$D(h, \delta) = \left[\frac{\int \left(\frac{\partial G(x+\delta, 0)}{\partial x} - \frac{\partial F(x, h)}{\partial x} \right)^2 dx}{\int dx} \right]^{1/2}, \quad (3)$$

in order to avoid the effect of misestimation of regional field of large wavelength.

In practical calculations, the infinite integral in the equation (2) is replaced by the numerical integration of finite length, and derivatives are also replaced by numerical differentiations. That is, equation (2) is converted into

$$F(x_i, h) = \frac{h}{\pi} \sum_{j=1}^N \frac{F(x_j, 0)}{(x_i - x_j)^2 + h^2} \Delta x \quad (4)$$

where N is the number of samples, and Δx is sampling interval in the direction of x -axis (perpendicular to the lineation), and also, numerical differentiations are given by

$$\Delta F(x_i, h) = [F(x_{i+1}, h) - F(x_i, h)] / \Delta x \quad (5)$$

and

$$\Delta G(x_i) = [G(x_{i+1}, 0) - G(x_i, 0)] / \Delta x \quad (6)$$

where $x_{i+1} = x_i + \Delta x$.

Here the measure of fitness $D(h, \delta)$ is defined by

$$D^2(h, \delta) = \frac{1}{M} \sum_{i=1}^M \{ \Delta G(x_i + \delta) - \Delta F(x_i, h) \}^2 \quad (7)$$

where M is the number of sample points to be fitted, and we look for the optimum value of h and δ which minimize the value D . This optimization is easily accomplished by calculation of (6) in every combination of possible values of h and δ . Here, the optimum value of h corresponds to the difference between distances to the anomalous body from the two lines of profiles.

RESULT AND DISCUSSION

The analytical procedure described in the previous section was applied to all combinations of the five magnetic profiles (No. 1–5) shown in *Figure 2*. In this analysis, sampling interval of 0.2 km was used in the direction of the profiles, which corresponded to about 0.18 km interval in the x -direction, and the number (N) of sample points per one profile was 1024. Of these sample points, 963 ($=M$) were actually used for curve fitting in order to reduce the edge effect of finite length. In order to obtain optimum value of h , minimum values of D (root mean square difference of longitudinal gradient) which were calculated under the scanning of δ value were plotted versus continuation distance h (*Fig. 3*). Here, the calculations were made at 0.1 km increment for h , and the same distance increment for δ as the sampling interval.

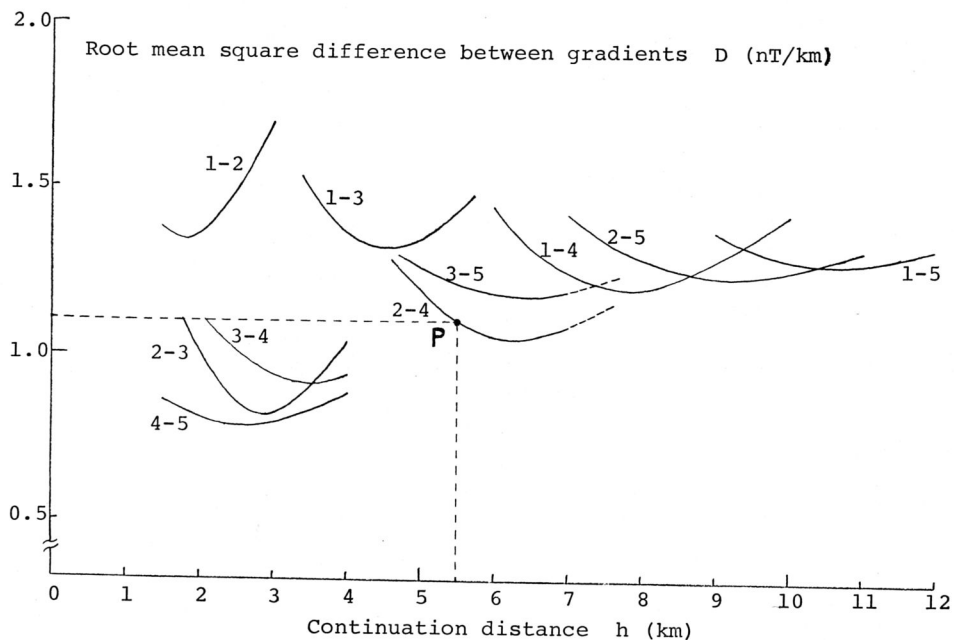


Figure 3. Root mean square differences (D , the measures of fitness) between two longitudinal gradients of profile $G(x, 0)$ and upward continued profile $F(x, h)$. There are 10 curves corresponding to the combination of the profiles, whose numbers are assigned to each curve. Of the two numbers, the left one is related to upward continued profile. For example, the point P in this illustration signifies that the measures of fitness (D) of upward continuation of No. 2 profile against No. 4 profile is 1.1 nT/km at the distance of 5.5 km. The lowermost point for each curve gives the optimum continuation distance h .

Every curve in *Figure 3* has a unique minimum, and optimum values are obtained directly. Those values are listed in *Table 1*, and illustrated in *Figure 4*, taking the distance to the anomalous body at No. 1 profile as a reference. Now from *Figure 4*, it is easy to infer that the anomalous body, or oceanic crust, has an inclination of around 15 degrees.

If we are to consider strict geometry, dip is a little larger than that represented in *Figure 4*, because the vertical axis of *Figure 4* is not the vertical depth but the distance to anomalous body. Even then, the dip angle is still around 15 degrees in this case, because deviation from the vertical depth is relatively small.

The result obtained above is compatible with other determinations of the inclination of the subducting oceanic plate. From the study of nearby deep earthquakes and hypocenter distribution of micro-earthquakes, the angle of subduction was determined to be 30 degrees beneath the Northeast Japan Island Arc (Hasegawa, Umino and Takagi, 1978). The other figure was derived from the multi-channel seismic reflection data across the Japan Trench (Ocean Research Institute, 1979), which yields the visual pattern of subsurface structure up to a certain depth. The estimated value of inclination is 5 degrees under the trench region. Consequently, the inclination of the subducting oceanic plate in the continental slope region which was determined by this study, lies between the values obtained for the trench and island arc regions.

Although these results are what would be expected, the location and the dip of the subducting plate obtained by this study do not agree completely with those for the island arc area. As shown in *Figure 5* the dip determined by the present study is too large to represent a continuous plate unless it has undulated shape. No evidence, however, of

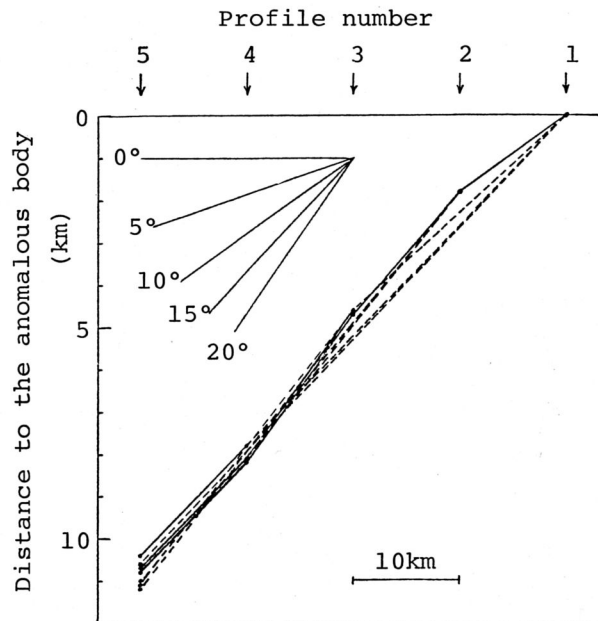


Figure 4. Illustration of optimum continuation distance h relative to No. 1 profile. This slope directly indicates the approximated dip of the anomalous body.

Table 1 Optimum continuation distance.

Upward continuation of the profile numbered in column-F is fitted to the profile in column-G at the continued distance of column-H.

F (No.)	G (No.)	H (km)
1	2	1.8
2	3	2.9
3	4	3.5
4	5	2.6
1	3	4.6
2	4	6.3
3	5	6.5
1	4	7.8
2	5	9.2
1	5	10.6

undulation of the plate has been discovered in this district. On the other hand, our analysis was based upon the assumption that the magnetic structure was two-dimensional. The actual structure is, however, never strictly two-dimensional, and we must be aware of the limitations which arise from our assumption.

It is possible that the effective magnetization of oceanic plate decreases as the plate descends deeper under the influence of tectonic processes. High temperature conditions at deeper locations may demagnetize the oceanic crust in relation to the Curie point.

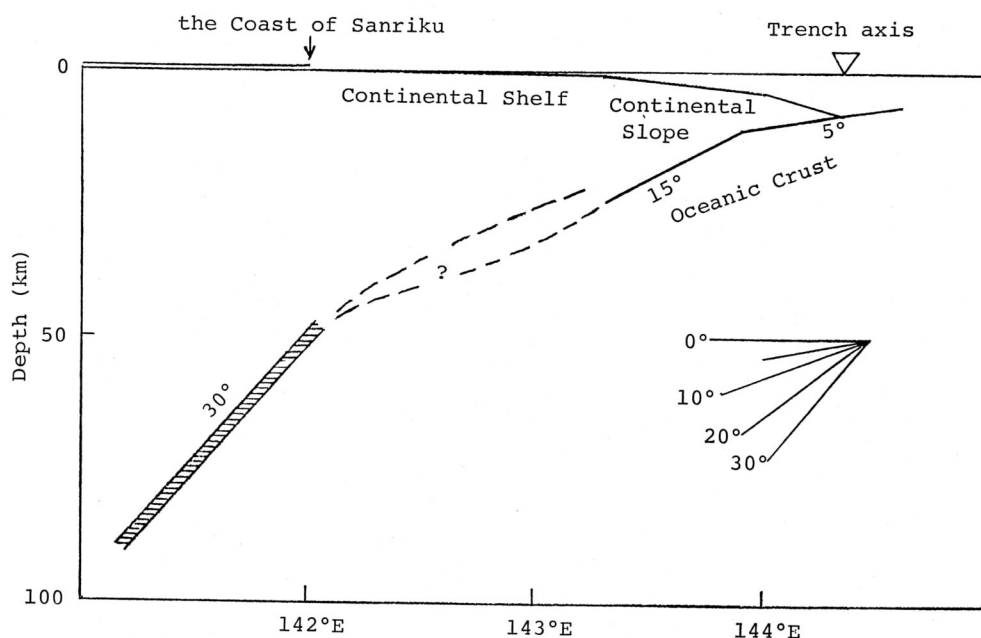


Figure 5. Schematic description of subducting oceanic crust in Sanriku District. The plate boundary dipping 30° beneath the island arc was determined from the study of earthquakes (Hasegawa, Umino and Takagi, 1978), and the gentle slope under the trench region from the seismic reflection data (Ocean Research Institute, 1979). The dip 15° or less under the region of continental slope is the result of this study.

These effects, if actually exist, will have deformed the result of analysis in such a manner that the calculated dip is greater than that of the actual structure.

It is concluded therefore, that the dip of the subducting oceanic plate under the continental slope off the Sanriku coast is approximately 15 degrees and that the figure might be somewhat lower owing to the deviation of the actual structure from the two-dimensional model used for the calculation.

ACKNOWLEDGMENT

We would like to express our thanks to Dr. Y. Shimazaki for his valuable suggestions and for critical reading of the manuscript.

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