Magnetization of Erimo Seamount

Toshitsugu YAMAZAKI

Marine Geology Department, Geological Survey of Japan, 1-1-3 Higashi, Tsukuba, Ibaraki 305, Japan

(Received January 5, 1988; Revised February 22, 1988)

The average magnetization vector of Erimo Seamount is obtained by a linear least squares inversion using the topographic and magnetic anomaly data acquired during the KAIKO project. As the dipole anomaly of the seamount is superimposed on the magnetic lineations of the oceanic crust, the contribution of the lineations was estimated using a two-dimensional block model, and was subtracted from the observed data before the inversion. The VGP (Virtual Geomagnetic Pole) position, 69°N, 321°E, is here proposed as the revision of the widespread value of UYEDA and RICHARDS (1966). Combined with the recently proposed ages of the seamount, 100 to 120 Ma, the VGP position provides an important clue in establishing the early Cretaceous pole position of the Pacific Plate.

The inversion assuming a planar regional field, which is the conventional way of removing the anomalies caused by bodies other than the seamount, was performed for comparison. The results differ considerably from those by the former procedure. The derived structure of the seamount (a thick non-magnetic cap) and the VGP position did not agree with the submersible observation and the age of the seamount, respectively. A planar regional field is not an adequate approximation of magnetic lineations.

1. Introduction

The average magnetization vector of a seamount can be estimated from the shape of the seamount and the magnetic anomalies over it. The magnetization vector indicates the latitude and the orientation of the plate underlying the seamount. This technique, the seamount paleomagnetism, plays a particularly important role in establishing polar wander paths of oceanic plates, such as the Pacific Plate, because paleomagnetic studies based on oriented rock samples are difficult to be conducted.

Erimo Seamount (Sisoev Seamount) is located on the seaward slope of the juncture of the Japan and the Kuril Trenches (Fig. 1). Magnetic study of this seamount was first carried out by UYEDA and RICHARDS (1966), and the VGP position of 56°N, 0°E was presented. This was the pioneering work on the paleomagnetism of seamounts. Together with the K–Ar age of 80 Ma by OZIMA *et al.* (1970), the VGP position of Erimo Seamount has been used widely as reliable data for determining the paleomagnetic pole position of the Pacific Plate during late Cretaceous, or at about 80 Ma (FRANCHETEAU *et al.*, 1970; HARRISON *et al.*, 1975; GORDON and COX, 1980; GORDON, 1983).

Fig. 1. Location of Erimo Seamount (stippled) and the Mesozoic magnetic lines M6 to M10. Topographic contours are at 1000 m intervals. Trenches deeper than 7000 m are shaded.

Many magnetic studies have clarified the distribution of the Mesozoic magnetic lineations in the Northwest Pacific (ex. UYEDA *et al.*, 1967; LARSON and CHASE, 1972; HILDE *et al.*, 1976; MURAKAMI *et al.*, 1977), and revealed that the magnetic anomalies produced by Erimo Seamount are superimposed on the magnetic lineations. UYEDA and RICHARDS (1966) determined the magnetization vector of the seamount and a planar regional field by inversion of the observed anomalies. This is a conventional and widely used way of seamount paleomagnetism (VACQUIER and UYEDA, 1967; FRANCHETEAU *et al.*, 1970; SAGER *et al.*, 1982; UEDA, 1985; McNUTT, 1986). But the assumption of a planar regional field for removing the effect of the magnetic anomalies caused by bodies other than the seamount should be used with caution (McNUTT, 1986). It is considered that a planar regional field may not be a good approximation to the contribution of magnetic lineations. Thus, there is some room for reconsideration for the magnetization of Erimo Seamount.

Recently, detailed geological and geophysical studies of Erimo Seamount were carried out by the French-Japanese co-operative KAIKO project (CADET *et al.*, 1987a, b). A rock sample obtained by the submersible "Nautile" has given an ^{40}Ar - ^{39}Ar plateau age of 104 ± 9 Ma (TAKIGAMI *et al.*, 1988). The free-air gravity anomalies suggest that the elastic thickness of the plate at the time of loading

(emplacement of the seamount) is only about 2 km (CADET *et al.*, 1987b). This means that the age of the seamount is close to that of the underlying oceanic crust, M8 (about 120 Ma, LARSON and HILDE, 1975). These results show that Erimo Seamount would be emplaced in early Cretaceous, much older than previously believed. Then, the magnetization of Erimo Seamount cannot be used as a reference for calculating the late Cretaceous pole position of the Pacific Plate.

In this paper, the magnetization of Erimo Seamount is re-examined and a revised paleomagnetic pole position is proposed. An improvement of the procedure is that the contribution of the magnetic lineations was evaluated using a two-dimensional block model, and was subtracted from the observed anomalies before the inversion. The result is compared with that by the conventional method, the inversion assuming a planar regional field. It is demonstrated that remarkable difference exists between the two results.

The geomagnetic polarity time scale of LARSON and HILDE (1975) was used in this paper. The declination and inclination of the present geomagnetic field at Erimo Seamount are -7° and 52° , respectively.

2. Bathymetric and Magnetic Data

Sea-Beam mapping and geophysical surveys (magnetism, gravity and seismic reflection) were carried out around Erimo Seamount along dense tracks (about 2 nautical mile intervals) during the KAIKO Project Phase I Leg. 3. Navigation control was done by Loran-C and GPS with accuracy better than 0.1 nautical mile. Compared with the magnetic anomaly data set of UYEDA and RICHARDS (1966), the quality of the new data set is enhanced by mainly the advance in the accuracy of positioning.

A bathymetric map in Fig. 2 (KAIKO I RESEARCH GROUP, 1986) shows that Erimo Seamount is now entering the trench. The seamount has a flat top covered with thin early Cretaceous limestone (CADET *et al.*, 1987a). The water depth of the summit is about 3800 m. The seamount is a little elongated in the NE-SW direction, and its maximum width is about 35 km. The volume of the seamount is approximately 1100 km^3 . It is a medium sized seamount in the Pacific.

A magnetic anomaly map around Erimo Seamount and the northern part of the Japan Trench shown in Fig. 3 (CADET *et al.*, 1987b) was obtained by subtracting the IGRF (International Geomagnetic Reference Field) 1980 from the measured total magnetic field. Corrections for the diurnal variation were not applied. Lineated magnetic anomalies with amplitude of about 300 nT are clearly shown, which reduces amplitude landward across the trench axis. They are correlated to M7 to M10 (119–122 Ma) of the Mesozoic polarity reversal sequence (CADET *et al.*, 1987b). A pair of positive (700 nT at maximum) and negative (-400 nT at minimum) anomaly centers over Erimo Seamount is superimposed on the positive and negative belts of the lineated anomalies, respectively. Another dipole anomaly on the inner trench slope northwest of Erimo Seamount is produced by an already subducted seamount (YAMAZAKI and OKAMURA, 1988).

Fig. 2. Sea-Beam bathymetric map around Erimo Seamount (KAIKO I RESEARCH GROUP, 1986). Contours are at 100 m intervals.

3. Seamount Paleomagnetism

3.1 Removal of the contribution of magnetic lineations

In this section, the procedure for removing the contribution of the magnetic lineations from the observed magnetic anomalies is described. As Erimo Seamount is situated on the outer-trench slope of the juncture of two trenches, a three-dimensional model should be used for a precise calculation of the contribution of the magnetic lineations of the oceanic crust underneath the seamount. But, the following approximation using a two-dimensional model is considered to be suitable.

First, subduction along the Kuril Trench alone was considered. The trench lies nearly parallel to the strike of the magnetic lineations. The magnetic anomalies expected on a line perpendicular to the strike of the lineations were calculated by a two-dimensional block model (Fig. 4). Detailed explanation of the parameters of this model is given later.

Next, subduction along the Japan Trench was taken into consideration. The amplitude of the anomalies was reduced depending on the distance from the trench

Fig. 3. Magnetic anomalies around Erimo Seamount and the northern part of the Japan Trench area (CADET, 1987b). Negative values are shaded. Contours are at 100 nT intervals. The dipole anomaly over Erimo Seamount is superimposed on magnetic lineations.

axis in a manner similar to that of the anomalies M9 and M10 which decreases landward (Fig. 3). As a result, a hypothetical distribution of lineated anomalies produced by the oceanic crust under Erimo Seamount was derived (Fig. 5(b)). The magnetic anomalies responsible for Erimo Seamount (Fig. 5(c)) are obtained by subtracting the estimated contribution of the lineations from the observed anomalies (Fig. 5(a)).

Parameters used for the block model are as follows. Thickness of the magnetized blocks was assumed to be 1 km. The depth of the oceanic crust is estimated from

Fig. 4. Magnetic anomalies produced by a two-dimensional block model. The magnetic polarity time scale of LARSON and HILDE (1975) is used. Solid blocks represent normal polarity and the open ones represent reversed polarity. Intensity of magnetization of 6 A/m, skewness parameter of -220° (LARSON and CHASE, 1972) and spreading rate of 5 cm/year are used. Broken lines show the position of Erimo Seamount. T: Axis of the Kuril Trench.

seismic reflection profiles (KAIKO I RESEARCH GROUP, 1986). The skewness parameter, a measure of asymmetry of the anomalies, was assumed to be -220° from the analyses of the Japanese lineation set by LARSON and CHASE (1972). Spreading rate of 5 cm/year and intensity of magnetization of 6 A/m were adopted. These two values make the amplitude and the wavelength of calculated lineations close to those of observations around Erimo Seamount.

3.2 Magnetization of Erimo Seamount

The method of TALWANI (1965) was used for calculating the magnetic anomalies from the seamount on the assumption of uniform magnetization. The depth contours were approximated as a stack of horizontal polygons (Fig. 5(f)). Using this topographic model, a linear least squares inversion of the magnetic anomalies after the contribution of the lineations was removed was performed to constrain the average magnetization vector of the seamount and a "regional field". In this case, a constant field would be suitable for the "regional field" because it is considered that only long-wavelength regional anomalies remain after the contribution of the magnetic lineations was removed. The induced magnetic field was assumed to be negligible compared to the magnetic field produced by the remanent magnetization.

The results of the computation are summarized in Table 1. The declination of 1° and the inclination of 36° are obtained, which gives the VGP position of 69°N , 321°E . These values are considerably different from those of UYEDA and RICHARDS (1966). The calculated anomalies are shown in Fig. 5(d). The residual anomalies (Fig. 5(e)) are generally less than 50 nT, and show no systematic trend. The goodness-of-fit ratio (VACQUIER and UYEDA, 1967) is 5.7.

Fig. 5. Observed magnetic anomalies and results of calculation by the procedure in which the contribution of magnetic lineations was estimated independently and was subtracted from the observed anomalies before the inversion. (a) Observed magnetic anomalies. Contours are at 50 nT intervals. (b) Contribution of the magnetic lineations. (c) Magnetic anomalies after the contribution of the lineations was subtracted. (d) Calculated magnetic anomalies. The sum of the anomalies from the seamount and a constant field. (e) Residual anomalies ((a)-(b)-(d)). (f) A cross section of the magnetic model. The seamount approximated by a stack of polygons rests on the oceanic crust of the two-dimensional blocks shown in Fig. 4.

Table 1. Results of the inversion of magnetic anomalies of Erimo Seamount.

Model	Declination (+east)	Inclination (+down)	Intensity (A/m)	Regional field ¹⁾				VGP position		
				Co (nT)	Cn (nT/km)	Ce (nT/km)	$G^2)$	Lat. (N)	Lon. (E)	
Magnetic lineations subtracted	1	36	5.8	57.3	0 ³⁾	0 ³⁾	5.7	69	321	
Planar regional field approximation										
(1) Uniform magnetization	-25	30	8.9	189.4	-0.68	-5.23	4.0	57	12	
(2) Top 800 m non-magnetic	-26	29	10.2	179.4	0.42	-6.04	4.4	56	14	
UYEDA and RICHARDS (1966)	-19	22	10.4	*	*	*	2.0	56	0	

¹⁾Co+Cn·x+Ce·y; x in the north direction, y in the east direction.²⁾Goodness-of-fit ratio (VACQUIER and UYEDA, 1967).³⁾Fixed to zero.

*A planar regional field was assumed but these coefficients were not given in the paper.

The reliability of the obtained direction of magnetization is estimated to be within several degrees. If no regional field is assumed, the calculated inclination of the magnetization is 6° deeper than in the case of the constant field and the goodness-of-fit ratio decreases to 3.1. Errors may result from ambiguity in the evaluation of the contribution of the magnetic lineations due to the uncertainty of the amplitude, wavelength and the position of the anomaly belts under the seamount. The values of the parameters of the block model were chosen so that the residual anomalies show no systematic trend like a lineation and that a high goodness-of-fit ratio is derived. Results of possible models other than the model presented in the Subsection 3.1 agreed within several degrees. For example, declination (D) and inclination (I) of 4° and 37° , respectively, are obtained if the intensity of the magnetization of the blocks is increased to be 7 A/m. A larger spreading rate of 5.7 cm/year gives the direction of 4° (D) and 37° (I). In the case of that the blocks are shifted 1 km southward relative to the seamount, the direction becomes 0° (D) and 31° (I).

3.3 Planar regional field model

For comparison, the computation was performed by the conventional procedure, that is, the average magnetization vector and a planar regional field were determined by the inversion of the raw data. In this method, the magnetic lineations were approximated by the planar field instead of being simulated independently.

As a result, the distance between the positive and negative anomaly centers of the calculated anomalies becomes shorter than that of the observed anomalies on the assumption that the whole seamount has uniform magnetization. The best fit model shown in Fig. 6 requires a thick (about 800 m) non-magnetic cap such as limestone on the seamount. The results of the direct observation of the seamount by the submersible "Nautilé", however, do not support the model with a thick non-magnetic cap. Basalts were taken at the depth of 3940 m (CADET *et al.*, 1987a), and limestone is probably less than 100 m in thickness. Therefore, the non-magnetic cap model requires that the magnetization of basalts of more than 600 m in thickness was lost by alteration, which seems to be geologically unrealistic. The results of the computation are given in Table 1. The direction of magnetization obtained by the planar regional field model is fairly close to that of UYEDA and RICHARDS (1966). This is a reasonable consequence considering that the method is basically the same. On the other hand, it differs significantly from the result by the model in which the effect of the magnetic lineations were evaluated independently.

4. Discussion

4.1 VGP position

The VGP positions derived from the two methods in this study and that of UYEDA and RICHARDS (1966) are plotted in Fig. 7. The apparent polar wander paths of the Pacific Plate proposed by SAGER and KEATING (1984) and COX and GORDON (1984) are also shown. The former is derived from the paleomagnetism of Pacific seamounts. The latter is mainly based on paleolatitudes of DSDP (Deep Sea Drilling

Fig. 6. Observed magnetic anomalies and results of calculation by the conventional procedure in which the inversion was performed assuming a planar regional field. That is, the magnetic lineations were approximated by the planar regional field. (a) Observed magnetic anomalies. Contours are at 50 nT intervals. (b) Calculated magnetic anomalies. The sum of the anomalies from the seamount and a planar regional field. (c) Residual anomalies. (d) A cross section of the magnetic model. To fit the observation, a non-magnetic cap of 800 m in thickness is required.

Project) cores, but the confidence ellipse of the pole position at 80 Ma (originally appeared in GORDON and COX (1980)) is based on the paleomagnetism of four seamounts including Erimo Seamount. The conventional planar regional field method including UYEDA and RICHARDS (1966) gives the VGP positions fairly close to the ellipses at 80 Ma and 81 Ma. But these do not agree with the recently proposed ages of Erimo Seamount, 100 to 120 Ma. On the other hand, the VGP position from the new procedure does not contradict the apparent polar wander path if the early Cretaceous pole exists between the curve of the late Jurassic pole position and the ellipse of mean Cretaceous of COX and GORDON (1984) or the ellipse at 91 Ma of SAGER and KEATING (1984).

Fig. 7. Comparison of the VGP position of Erimo Seamount with apparent polar wander paths of the Pacific Plate. The star is the VGP position of Erimo Seamount by the method in which the contribution of the lineations was subtracted before the inversion. The open square is the VGP position from the planar regional field model. The solid square is the VGP position of UYEDA and RICHARDS (1966). The shaded ellipses are the pole positions of the Pacific Plate proposed by SAGER and KEATING (1984). The bold curves are the polar wander path of COX and GORDON (1984). The broken lines show the pole position estimated from the skewness of the magnetic lineations M1 to M10 by LARSON and CHASE (1972).

The apparent polar wander path of the Pacific Plate before 100 Ma is, however, poorly determined at present. The late Jurassic pole position of COX and GORDON (1984) rests upon the result from only one DSDP site. LARSON and CHASE (1972) obtained the early Cretaceous pole position from the skewness of the Mesozoic magnetic lineations M1 to M10 (a polygon in Fig. 7). This does not agree with the pole position of Erimo Seamount although the seamount was emplaced soon (within about 20 m.y.) after the underlying oceanic crust of the age of M8 was formed.

The validity of a paleomagnetic pole determined by the skewness of magnetic anomalies is at present controversial. CANDE (1976) observed a systematic discrepancy of 12° to 14° in the skewness of late Cretaceous to early Paleogene anomaly sequence 27 to 32 in the North and the South Pacific. He also suggested a possibility of the existence of anomalous skewness in the anomalies M1 to M10. RAYMOND and LABRECQUE (1987) proposed a model of the magnetization of the oceanic crust in which the chemical remanent magnetization takes an important role. This model predicts the skewness discrepancies of magnetic anomalies.

On the other hand, one can not rely much on the pole position from a single seamount. There is a possibility that the pole position of Erimo Seamount is distorted by the effects of the induced magnetization and/or the viscous remanent magnetization (VRM). The contribution of the induction and VRM to the magnetization of seamounts is considered to be small in general (SAGER, 1987), but the rock magnetic characteristics of the interior of seamounts have not yet been studied in detail. The only rock magnetic example to justify it is the results of DSDP basalts from Suiko Seamount (KONO, 1980). This site, the deepest hole on seamounts, penetrated about 400 m of basaltic layer. The mean of the Königsberger ratio, 9.37, is high enough to be interpreted with a remanent magnetization model.

More works on the paleomagnetism of seamounts in the Northwest Pacific underlain by the old oceanic crust are needed for better understanding of the movement of the Pacific Plate in early Cretaceous or in earlier times.

4.2 Implications for seamount paleomagnetism

In this paper, I have demonstrated that the result of the inversion of the anomalies after the contribution of the magnetic lineations was removed independently is considerably different from the result of the inversion of the raw data assuming a planar regional field. It is revealed that the planar field is not an adequate approximation of the magnetic lineations.

The oceanic crust generally produces magnetic lineations except for the crust in the Cretaceous Magnetic Quiet Zone or the Jurassic Magnetic Quiet Zone. It is, therefore, considered that magnetic anomalies over a seamount often include some contribution of the magnetization of the oceanic crust beneath the seamount. In such cases, simulation of magnetic lineations based on a proper model is necessary. For evaluating the effect of magnetic lineations correctly, the extent of magnetic survey for the seamount paleomagnetism should be wide enough so that the distribution of magnetic lineations around an objective seamount can be known. The published results of the seamount paleomagnetism rarely took the magnetic lineations into account and usually assumed a planar regional field at the inversion. It is necessary that these results are used with caution.

5. Conclusions

1) The magnetization of Erimo Seamount has been determined by the inversion of the magnetic anomalies after the contribution of the magnetic lineations which are evaluated using a two-dimensional block model was subtracted. The new VGP position, 69°N, 321°E, has been proposed as the revision of the widely used value of UYEDA and RICHARDS (1966).

2) The result by the conventional method, the inversion of raw data assuming a planar regional field, required a thick non-magnetic part on the seamount, but this is not supported by the submersible observation. The derived VGP position is not in accordance with the apparent polar wander path of the Pacific Plate. A planar regional field is inadequate approximation for magnetic lineations.

3) Based on the recently proposed age of Erimo Seamount, 100 Ma to 120 Ma, the VGP position of Erimo Seamount provide important basic data in clarifying the movement of the Pacific Plate during early Cretaceous. More works on the seamount paleomagnetism are needed to establish the early Cretaceous pole position of the Pacific Plate.

I thank Profs. K. Kobayashi, A. Mizumo and Dr. Y. Shimazaki for giving me the opportunity to join the KAIKO project and for encouragement. The author is greatly indebted to Dr. Isezaki who suggested the importance of magnetic lineations on the seamount paleomagnetism. The KAIKO project was supported on the Japanese side by the Ministry of Education and Culture and ORI and on the French side by CNRS and IFREMER. The magnetic inversion studies were supported by Geological Survey of Japan.

REFERENCES

- CADET, J.-P., K. KOBAYASHI, S. LALLEMAND, L. JOLIVET, J. AUBOUIN, J. BOULÈGUE, J. DUBOIS, H. HOTTA, T. ISHII, K. KONISHI, N. NIITSUMA, and H. SHIMAMURA, Deep scientific dives in the Japan and Kuril Trenches, *Earth Planet. Sci. Lett.*, **83**, 313–328, 1987a.
- CADET, J.-P., K. KOBAYASHI, J. AUBOUIN, J. BOULÈGUE, C. DEPLUS, J. DUBOIS, R. VON HUENE, L. JOLIVET, T. KANAZAWA, J. KASAHARA, K. KOIZUMI, S. LALLEMAND, Y. NAKAMURA, G. PAUTOT, K. SUYEHIRO, S. TANI, H. TOKUYAMA, and T. YAMAZAKI, The Japan Trench and its juncture with the Kuril Trench: cruise results of the Kaiko project, Leg 3, *Earth Planet. Sci. Lett.*, **83**, 267–284, 1987b.
- CANDE, S. C., A paleomagnetic pole from late Cretaceous marine magnetic anomalies in the Pacific, *Geophys. J. R. astr. Soc.*, **44**, 547–566, 1976.
- COX, A. and R. G. GORDON, Paleolatitudes determined from paleomagnetic data from vertical cores, *Rev. Geophys. Space Phys.*, **22**, 47–72, 1984.
- FRANCHETEAU, J., C. G. A. HARRISON, J. G. SCLATER, and M. L. RICHARDS, Magnetization of Pacific seamounts: a preliminary polar curve for the northeastern Pacific, *J. Geophys. Res.*, **75**, 2035–2061, 1970.
- GORDON, R. G., Late Cretaceous apparent polar wander of the Pacific Plate: evidence for a rapid shift of the Pacific hotspots with respect to the spin axis, *Geophys. Res. Lett.*, **10**, 709–712, 1983.
- GORDON, R. G. and A. COX, Calculating palaeomagnetic poles for oceanic plates, *Geophys. J. R. astr. Soc.*, **63**, 619–640, 1980.
- HARRISON, C. G. A., R. D. JARRARD, V. VACQUIER, and R. L. LARSON, Palaeomagnetic of Cretaceous Pacific seamounts, *Geophys. J. R. astr. Soc.*, **42**, 859–882, 1975.
- HILDE, T. W. C., N. ISEZAKI, and J. M. WAGEMAN, Mesozoic sea-floor spreading in the North Pacific, in *The Geophysics of the Pacific Ocean Basin and Its Margin* (Geophysical monograph Vol. 19), edited by G. H. Sutton *et al.*, pp. 205–226, American Geophysical Union, Washington D.C., 1976.
- KAIKO I RESEARCH GROUP, *Topography and Structure of Trenches around Japan—Data Atlas of Franco-Japanese KAIKO Project, Phase I*, 305 pp., University of Tokyo Press, Tokyo, 1986.
- KONO, M., Magnetic properties of DSDP Leg 55 basalts, in *Initial Reports of the Deep Sea Drilling Project*, Vol. 55, edited by E. D. Jackson and I. Koizumi, *et al.*, pp. 723–736, U.S. Government Printing Office, Washington D.C., 1980.
- LARSON, R. L. and C. G. CHASE, Late Mesozoic evolution of the western Pacific ocean, *Geol. Soc. Amer. Bull.*, **83**, 3627–3644, 1972.
- LARSON, R. L. and T. W. C. HILDE, A revised time scale of magnetic reversals for the early Cretaceous and late Jurassic, *J. Geophys. Res.*, **80**, 2586–2594, 1975.
- MCNUTT, M., Nonuniform magnetization of seamounts: a least squares approach, *J. Geophys. Res.*, **91**, 3686–3700, 1986.

- MURAKAMI, F., K. TAMAKI, and K. NISHIMURA, Geomagnetic survey, *Geol. Surv. Japan Cruise Rept.*, **7**, 43-49, 1977.
- OZIMA, M., I. KANEOKA, and S. ARAMAKI, K-Ar ages of submarine basalts dredged from seamounts in the western Pacific area and discussion of oceanic crust, *Earth Planet. Sci. Lett.*, **8**, 237-249, 1970.
- RAYMOND, C. A. and J. L. LABRECQUE, Magnetization of the oceanic crust: thermoremanent magnetization of chemical remanent magnetization?, *J. Geophys. Res.*, **92**, 8077-8088, 1987.
- SAGER, W. W., Late Eocene and Maastrichtian paleomagnetic poles for the Pacific plate: implications for the validity of seamount paleomagnetic data, *Tectonophysics*, **144**, 301-314, 1987.
- SAGER, W. W. and B. H. KEATING, Paleomagnetism of Line Islands seamounts: evidence for late Cretaceous and early Tertiary volcanism, *J. Geophys. Res.*, **89**, 11135-11151, 1984.
- SAGER, W. W., G. T. DAVIS, B. H. KEATING, and J. A. PHILPOTTS, A geophysical and geologic study of Nagata Seamount, northern Line Islands, *J. Geomag. Geoelectr.*, **34**, 283-305, 1982.
- TAKIGAMI, Y., I. KANEOKA, T. ISHII, and Y. NAKAMURA, ^{40}Ar - ^{39}Ar ages of igneous rocks recovered from Daiichi-Kashima and Erimo Seamounts during the KAIKO Project, *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, 1988 (in press).
- TALWANI, M., Computation with the help of a digital computer of magnetic anomalies caused by bodies of arbitrary shape, *Geophysics*, **30**, 797-817, 1965.
- UEDA, Y., Geomagnetic study on Seamounts Daiiti-Kasima and Katori with special reference to a subduction process of Daiiti-Kasima, *J. Geomag. Geoelectr.*, **37**, 601-625, 1985.
- UYEDA, S. and M. RICHARDS, Magnetization of four Pacific seamounts near the Japanese Islands, *Bull. Earthq. Res. Inst.*, **44**, 179-213, 1966.
- UYEDA, S., V. VACQUIER, M. YASUI, J. SCLATER, T. SATO, J. LAWSON, T. WATANABE, F. DIXON, E. SILVER, Y. FUKAO, K. SUDO, M. NISHIKAWA, and T. TANAKA, Results of geomagnetic survey during the cruise of R/V Argo in western Pacific 1966 and the compilation of magnetic charts of the same area, *Bull. Earthq. Res. Inst.*, **45**, 799-814, 1967.
- VACQUIER, V. and S. UYEDA, Palaeomagnetism of nine seamounts in the western Pacific and of three volcanoes in Japan, *Bull. Earthq. Res. Inst.*, **45**, 815-848, 1967.
- YAMAZAKI, T. and Y. OKAMURA, Subducting seamounts and deformation of overriding forearc wedges around Japan, *Tectonophysics*, 1988 (in press).