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Oceanic structures in the vicinity of Komahashi Daini Kaizan, a seamount in the Kyushu-Palau Ridge
Part Ⅱ. Velocity Fields

Yoshihiko SEKINE*

Abstract : Hydrographic observations in the vicinity of a seamount, Komahashi Daini Kaizan, located in the northwestern part of the Philippine Basin south of Japan, were carried out six times from 1989 to 1993. As the results on the temperature and salinity fields obtained by these cruises have been reported in Part I, results of velocity fields by ADCP are presented in this paper. Most of the observed velocity by ADCP goes over the seamount, Komahashi Daini Kaizan and a tendency to flow along the isopleth of the depth of the seamount is shown to be weak, which indicates the topographic effect of the seamount does not reach to the deepest level of ADCP data of 150 m–200 m. This result agrees with Part I which shows that the observed Rossby height (fL/N) and the observed baroclinic Taylor column estimated from the change in isotherm and isohaline are smaller than the representative depth of the seamount. In July, 1989, vertically coherent large northward velocity was observed in association with the formation of small meander path of the Kuroshio southeast of Kyushu. The attainment of geostrophic balance is checked by the correlation between the observed vertical difference of geostrophic flow and that of ADCP velocity. Although positive correlation is detected between the two velocity differences, they do not show clear linear relation. This suggests that non-geostrophic flow component is prominent in the vicinity of this seamount.

Key words : *Komahashi Daini Kaizan, Kyushu-Palau Ridge, topographic effect, sea mount*

1. Introduction

The interaction of ocean currents with seamounts has been of interest to the oceanic community (e.g., HOGG, 1980; RODEN, 1987). Generation of internal waves, trapping and/or generation of eddies and uplift of deeper layer water are possible by the topographic effects of a seamount. The effects of a seamount generally depend on the vertical structure of the Taylor column formed over the seamount (e.g., HOGG, 1973; JOHNSON, 1977). If the water has a homogeneous density and the nonlinear effect is relatively small, a barotropic Taylor column with vertically coherent flow is formed and the topographic effect of the seamount extends to the surface layer. If these two conditions are not satisfied, the Taylor column has a tendency to be restricted to a deeper level below the Rossby height fL/N (e.g., GILL, 1982), where f is the Coriolis parameter, L the half of the representative horizontal scale of seamount with a depth of $h_0/(1+(x/L)^2)$, where h_0 is a height of the peak of the seamount from ocean basin and x a horizontal distance from the peak and N the Brunt-Väisälä frequency assumed constant.

Furthermore, the topographic effect of an elliptic seamount placed at various angles to a uniform barotropic flow was examined by JOHNSON (1982) and the planetary β effect on the topographic effect of a seamount was examined by MCCARTNEY (1975) and VERRON and LE PROVOST (1985). The detailed time change of the topographic effect was studied by HUPPERT and BRYAN (1975).

Although there have been various theoretical studies, the observations on the topographic effect of the seamount have not been fully carried out. Because oceanic conditions are different for each seamount, specified

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* Institute of Oceanography, Faculty of Bioresources, Mie University, 1515 Kamihama, Tsu, Mie, 514–8507 Japan

observations on the topographic effect of seamount are needed for each seamount. In part I of this study (SEKINE, 2001), the observed oceanic conditions over the seamount "Komahashi Daini Kaizan" in the Kyushu-Palau Ridge in the Philippine Basin was reported with reference to temperature and salinity fields. In the present paper, the observed velocity fields in the vicinity of Komahashi Daini Kaizan is reported as a Part II of this study.

2. Observations

Observations have been carried out using the Training Vessel " Seisui-maru " of Mie University from 1989 to 1993. An acoustic doppler current profiler (ADCP) was used to observe the horizontal velocity along CTD observational lines, of which details have been mentioned in Part I. The ADCP data averaged every ten minites with the accuacy of 5 cm sec^{-1} were corrected by use of GPS data and loran C data. Only the ADCP velocity observed during constant ship speed are analyzed in the present study.

3. Results of observations

Velocity fields observed by ADCP is shown in Fig. 1. In KS-89JUL1 (Fig. 1a) observed from 14 to 16 in July 1989, southward flow dominates at 50 m, but northward flow dominates at 100 m and 150 m. Coherent flows are found at 100 m and 150 m, except for the western area of the seamount.

Vertically coherent strong northeastward flow is observed in KS-89JUL2 (Fig. 2b) observed from 22 to 24 in July 1989. As this observation is made about one week after KS-89JUL1 (Fig. 1a), very significant change in the flow pattern is detected. A small meander of the Kuroshio off Kyushu is formed in this observational period (Part I) and the strong northeastward flow is associated with the small meander of the Kuroshio. It should be noticed that the large meander of the Kuroshio is formed by the eastward shift of the small meander southeast of Kyushu and its abrupt amplification in south of Kii Peninsula (SHOJI, 1972; SOLOMON, 1978; SEKINE and TOBA, 1981a). In particular, SEKINE and TOBA (1981b) pointed out by the numerical experiments that the small meander can be generated by the stretching of the water column over the continental slope, when the current velocity of the Kuroshio is abruptly increased. Similar results were obtained by ENDOH and HIBIYA (2000) by use of a flat bottom model, in which small meander is formed by the coastal topographic effect of Kyushu during the period of increase in the Kuroshio velocity.

During KS-89DEC (Fig. 1c), vertically coherent northwestward flow was seen east of the seamount. Together with the southwestward flow west of the seamount, existence of cyclonic circulation is suggested over and around the seamount. Vertically coherent flow is detected in KS-90MAY (Fig. 1d). In KS-93JUL (Fig. 1e), coherent eastward flow is observed in the northern region at depths 50 m and 100 m. Although the flow is vertically coherent down to 200 m in the east, clear eastward flow at 200 m is not found in the north.

If the topographic effect of the seamount is prominent in the upper layer, there is a tendency that the flow over the seamount has a tendency to flow along contours of ambient potential vorticity f/h, which is well approximated by the contours of h (isopleth of depth). Here, as the topographic effect is relatively prominent in the deeper layer, we notice the ADCP velocity at the deepest layer near the seamount.

In KS-JUL1 (Fig. 1a), as the northward flow goes over the top of the seamount, the velocity pattern shows no tendency to flow along isopleth of depth. In KS-89JUL2 (Fig. 1b), the small meander flow goes over the seamount. Because the inertial effect of the small meander is so large (SEKINE and TOBA, 1981ab; ENDOH and HIBIYA, 2000), and because horizontal scale of the small meander is much larger than the scale of the seamount, it is suggested that the small meander can go eastward over the seamount.

The southwestward flows goes over the seamount in KS-89DEC (Fig. 1c) and KS-90MAY (Fig. 1d), while the northeastward flow also goes over the seamount in KS-93JUL (Fig. 1e). On the whole, most of the flow goes over the top of seamount and tendency to flow along the isopleth of the depth of the seamount

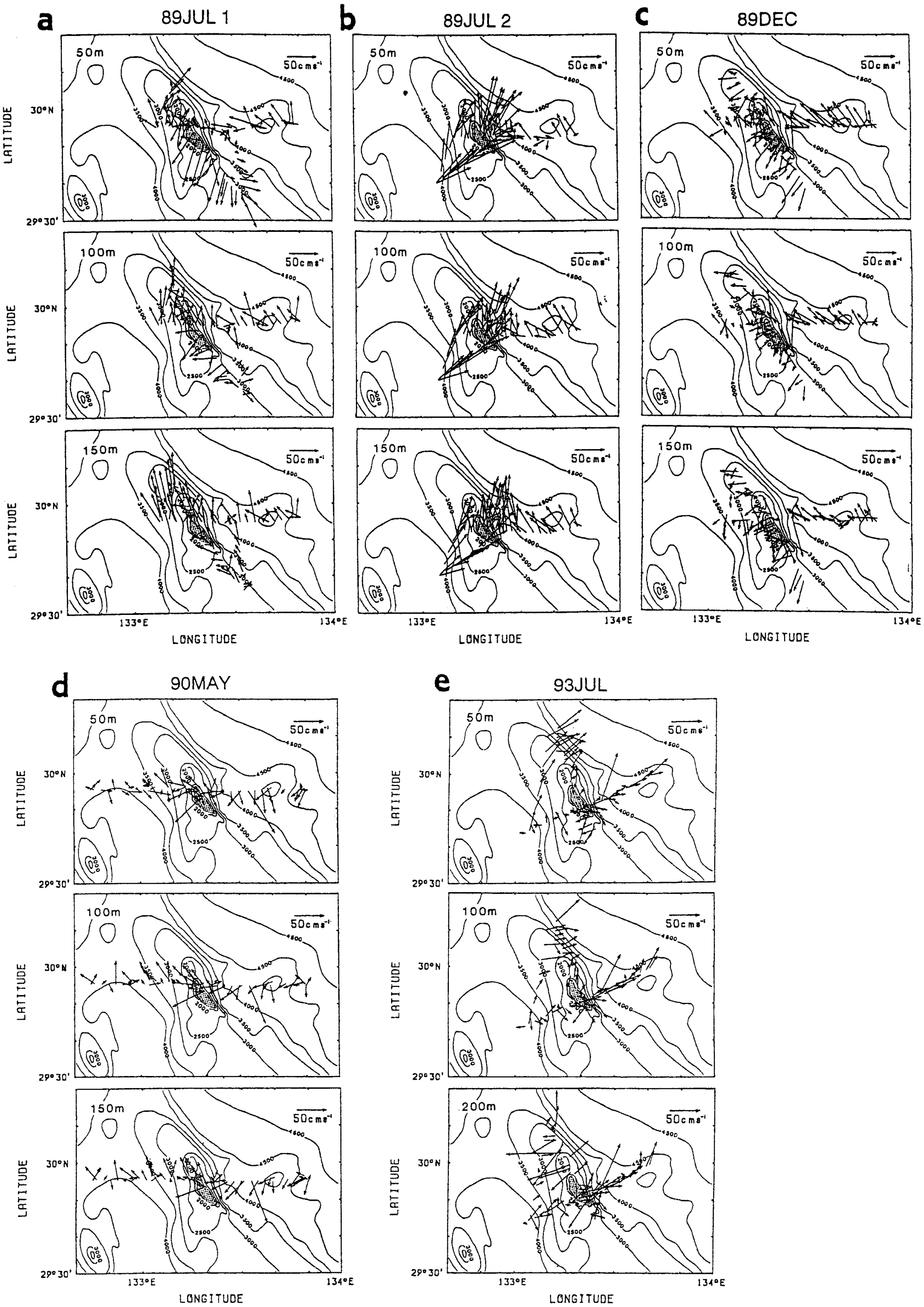

Fig. 1. Horizontal velocity observed by ADCP during (a) KS-89JUL1, (b) KS-89JUL2, (c) KS-89DEC, (d)KS-90MAY and (e) KS-93JUL. Isopleths of depths (in meters) are also shown in top left of each panel. Region shallower than 1500 m is stippled.

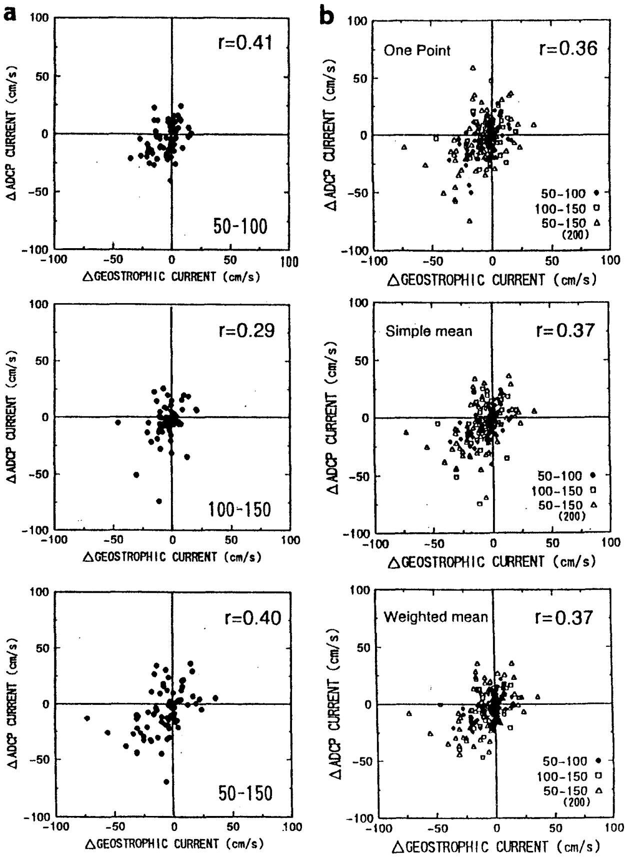

Fig. 2. (a) Correlation between the vertical differences of geostrophic velocity and of observed ADCP velocity. The vertical difference of ADCP is estimated as mean of all the ADCP velocities observed between two neighboring CTD stations. Two levels (in depth) to estimate the velocity difference are shown right bottom and the correlation coefficient (r) is shown in the upper right of each panel. (b) Correlation between the vertical geostrophic flow difference and observed ADCP velocity difference at 50 ~ 150 m. ADCP velocity is estimetd as one ADCP data nearest to the middle point of the two neighboring CTD stations (top) and same as in (a) (middle) and as the weighted mean of all the ADCP velocity, in which the weight is inversely proportional to the distance of the ADCP station from the middle point between two CTD stations (bottom).

is shown to be weak, which indicates the topographic effect of the seamount does not reach to the deepest level of ADCP data of 150 m–200 m. This result agrees with Part I, in which the observed Rossby height (*fL*/*N*) and the observed baroclinic Taylor column estimated from the change in isotherm and isohaline are smaller than the representative depth of the Komahasi Daini Kaizan, which indicates that the topographic effect of the Komahashi Daini Kaizan does not reach to the surface.

In order to see the attainment of the geostrophic balance over the seamount, correlation between the vertical difference of geostrophic flow and that of velocity observed by ADCP is shown in Fig. 2. Here, we should notice that the vertical difference of the geostrophic flow does not depend on the selection of the reference level (Fig. 3). Namely, the constant barotropic flow due to the unknown surface pressure gradient equally acts on the internal layer, it is eliminated by the difference of two internal levels. Here, ADCP velocity is estimated as the simple mean of all ADCP

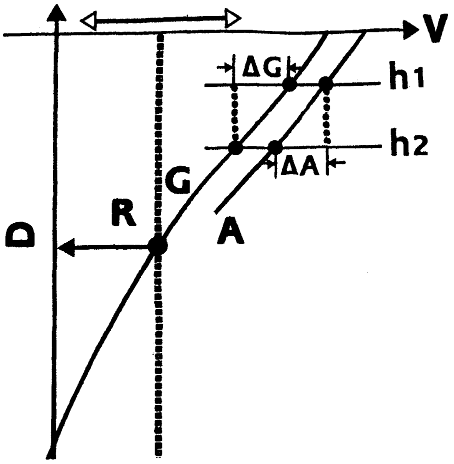

Fig. 3. Schematic representation of the analysis to see the attainment of the geostrophic flow balance. Horizontal (vertical) axis shows the velocity (depth). Because only the vertical Geostrophic flow profile (G) is obtained by the geostrophic flow estimation, actual geostrophic velocity shifts parallel to horizontal axis illustrated by open arrows, which depends on the adoption of the reference level shown by R. This effect can be negected, if we consider the vertical geostrophic flow difference at two different depth, H1 and H2. So attainment of the geostrophic flow balance is examined by comparing the vertical velocity difference of the geostrophic flow and that of ADCP velocity (A).

velocity data between two neighboring CTD stations. It is shown from Fig. 2a that although positive correlation exceeds the confidence limit of 95 % with the correlation coefficient ($\gamma = 0.24$), two velocity differences do not shows clear linear relationship.

Because there are several observed ADCP velocities between two neighboring CTD stations, other two ADCP velocities are estimated : the first is one ADCP data nearest to the middle point of the two neighboring CTD stations and the second is estimated as the weighted mean of all the ADCP velocity between two neighboring CTD stations, in which the weight is inversely proportional to the distance of the ADCP station from the middle point between two CTD stations. It is shown from Fig. 2b that they show no significant systematic difference and the correlation coefficient is almost equal. This means that there exists a non-geostrophic flow component such as the tidal current, the wind-drift flow and/or the Ekman flow, which agrees with the case of the seamount Daini Kinan Kaizan (SEKINE and HAYASHI, 1992) and Tosa-bae (SEKINE *et al.*, 1994).

5. Summary and discussion

The hydrographic observations around Komahashi Daini Kaizan south of Japan were made by the Training Vessel "Seisui-maru" of Mie University six times from 1989 to 1993. As a Part II of this study, observed velocity by use of ADCP is reported in the present paper. Main results are summarized as follows.

(1) Almost of the flow goes over the seamount and tendency to flow along the isopleth of the depth of the seamount is shown to be weak (Fig. 1), which indicates the topographic effect of the seamount does not reach to the deepest level of ADCP data of 150 m–200 m. This result agrees with Part I in which the observed Rossby height (fL/N) and the observed baroclinic Taylor column estimated from the change in isotherm and isohaline are shown to be smaller than the representative depth of the seamount.

(2) In KS–89JUL2 (Fig. 1b), vertically coherent large northward velocity was observed in association with the formation of small meander path of the Kuroshio southeast of Kyushu. As this observation is made about one week after KS–89JUL1 (Fig. 1a), significant change in the velocity fields is detected. The approach of the Kuroshio has a large influence on the oceanic condition of this seamount.

(3) In order to see the attainment of geostrophic balance, correlation between the vertical difference of geostrophic flow and that of ADCP velocity has been examined. Although significant positive correlation is obtained between the two velocity differences, they do not show clear linear relation. Non-geostrophic flow component is not negligible in the vicinity of this seamount in the upper layer shallower than 150–200 m.

Non-geostrophic flow component is important in the upper layer, which is mentioned in (3). In relation to this, it should be noted that ADCP velocity is often used as a reference velocity of the geostrophic flow estimation. However, there is a possibility that the geostrophic flow balance is not established in the ADCP velocity (3). As the check of the attainment of the geostrophic balance (Fig. 3) is easily carried out, such a check is needed if ADCP velocity is used as a reference level velocity. In relation to this, it should be also noted that we have no clear method to filter the contribution of the vertical change in the isotherms and isohalines which has no relationship of the geostrophic flow balance such as internal wave. Namely, all the vertical changes in isotherms and isohaline are not associated with the geostrophic flow balance and their contribution on the pressure gradient is included in the geostrophic flow estimation. Some correlation method which excludes the internal pressure gradient by non-geostrophic temperature and salinity variations is needed for the exact estimation of geostrophic flow.

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