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Oceanic structures in the vicinity of Komahashi Daini Kaizan, a seamount in the Kyushu-Palau Ridge
Part I. Temperature and salinity fields

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Abstract : Hydrographic observations by use of CTD and ADCP in the vicinity of a seamount, Komahashi Daini Kaizan, located in the Kyushu-Palau Ridge, were carried out six times from 1989 to 1993. Results of the observed temperature and salinity fields are presented in this paper, as a Part I of this study. Various kinds of vertical shift of isotherms, isohalines and isopycnals are observed around the seamount. It is also shown that the less saline water less than 34.2 psu corresponding to the North Pacific Intermediate water is not observed over the top of this seamount, while the less saline water is observed off the topography of the seamount, which is due to enhanced vertical mixing by the internal wave over the top of seamount and/or the topographic effect of the seamount which forces a less saline water to flow along isopleth of depth of the seamount. In July 1989, the siginificant changes in the temperature and salinity fields are observed during only one week by the approach of small meander of the Kuroshio generated in southeast of Kyushu. Almost estimated Rossby heights (fL/N) are smaller than the peak depth of the seamount (289 m), and the observed height of the baroclinic Taylor column evaluated from the vertical displacement of isotherms and isohalines does not reach to the surface layer, both of which shows that the topographic effect of the seamount does not reach to the sea surface.

Key words : *Komahashi Daini Kaizan, North Pacific Intermediate water, sea mount*

1. Introduction

In the northern Philippine Basin, there have been several observations on the topographic effect of seamount. FUKASAWA and NAGATA (1978; 1980) observed the oceanic structure near the Shoal Kokushou-sone located in southwest of Kyushu. Upwelling along the northern slope of the shoal was shown by the temperature observation (FUKASAWA and NAGATA, 1978), while upwelling along southern slope was detected in June 1977 (FUKASAWA and NAGATA, 1980). Furthermore, FUKASAWA (1983) suggested that distribution of isothermal layers is a helpful indicator of the nature of oceanic structures in the vicinity of the shoal Kokushou-sone. SEKINE and MATSUDA (1987a, b) made hydrographic observations over a bump Tosa-Bae off Shikoku south of Japan (Fig. 1a). They observed a cold eddy west of this bump and a warm eddy east of it. In the later observations (SEKINE *et al.*, 1994), salinity minimum water was found on the northern side of the Tosa-Bae, which suggested the westward intrusion of less saline water over the northern slope. KONAGA and NISHIYAMA (1978) and KONAGA *et al.* (1980) observed that a cold eddy detached from the Kuroshio large meander was trapped over a seamount, the Daini Kinan Kaizan (Fig. 1a). SEKINE and HAYASHI (1992) observed that vertical shift of isotherm and isohaline above the top of the seamount, Daini Kinan Kaizan (Fig. 1a) was maintained more than 10 days, which suggested that the vertical shifts of the isotherm and isohaline are rather stable.

In the present study, oceanic structures over the seamount "Komahashi Daini Kaizan (Fig. 1a) are studied by use of the observational data of six cruises (Table 1). The Komahashi Daini

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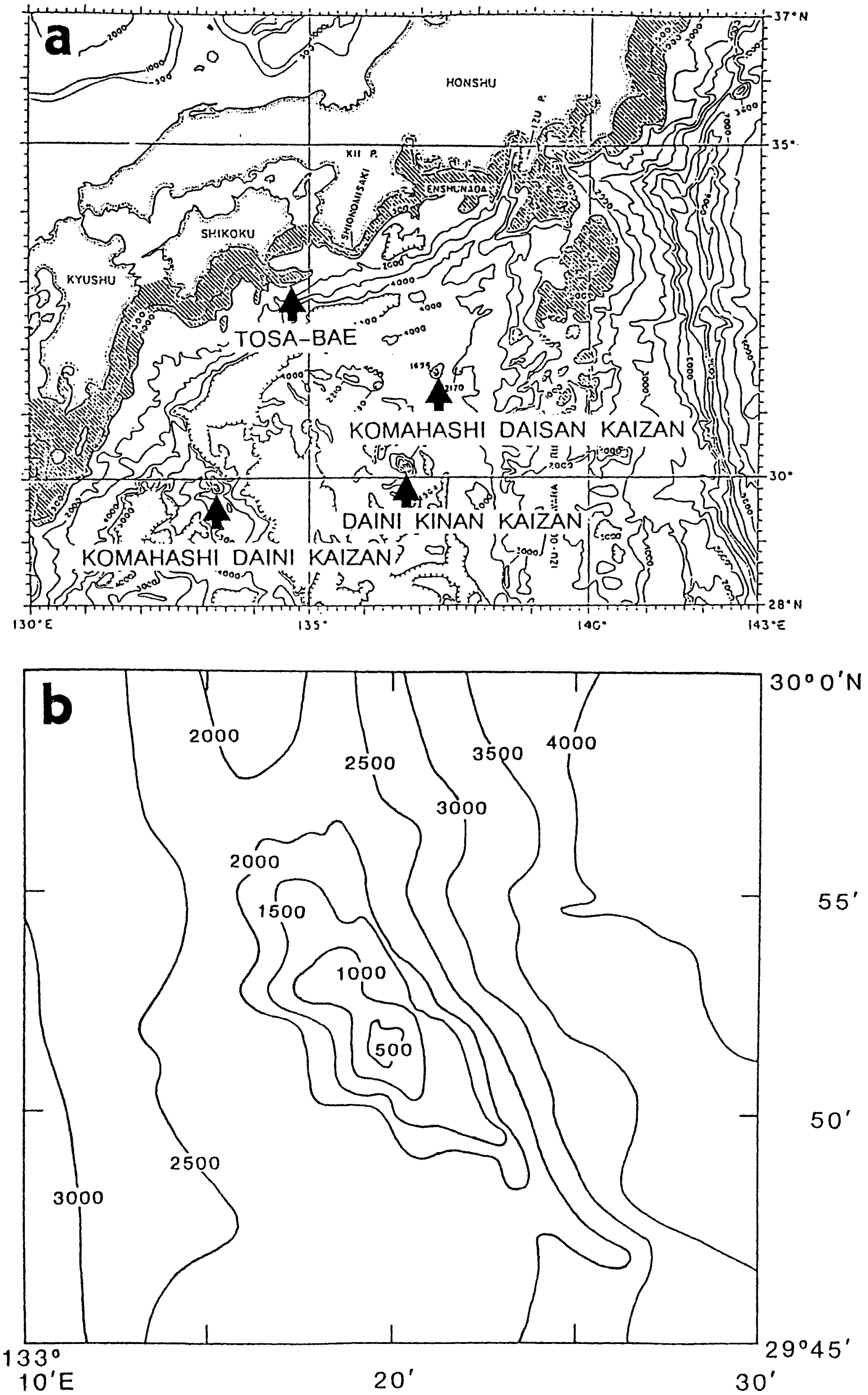

Fig. 1. (a). Location of the seamount "Komahashi Daini Kaizan" and other seamounts south of Japan. Isopleths of depth (in meter) are also shown (after TAFT, 1972). (b) Bathymetry in the vicinity of the Komahashi Daini Kaizan.

Table 1. Hydrographic observations around Komahashi Daini Kaizan.

Cruise Name	Periods of Observation	Obsercvational line	Main instruments
KS-89JUL1	14–16 Jul. 1989	**a, b**	CTD and ADCP
KS-89JUL2	22–24 Jul. 1989	**c, d, e**	CTD and ADCP
KS-89DEC	5– 7 Dec. 1989	**f, g**	CTD and ADCP
KS-90MAY	19–21 May. 1990	**h**	CTD and ADCP
KS-90JUL	13–14 Jul. 1990	**i, j, k**	Mi-com. BT
KS-93JUL	16–17 Jul. 1993	**l, m**	CTD, XBT and ADCP

Kaizan is located in the Kyushu-Palau Ridge. This seamount has an elliptic shape (Fig. 1b), of which 1000 m isopleth has a long axis of about 8 km from southeast to northwest and a short axis of about 4 km from southwest to northeast. The depth at the peak of this seamount is 289 m. In periods of a small meander path of the Kuroshio off Kyushu (SHOJI, 1972; SOLOMON, 1978; SEKINE and TOBA, 1981), the main axis of the Kuroshio approaches to this seamount. It is noted that there have been no detailed hydrographic observations over this seamount. Therefore, we have made six hydrographic observations in its vicinity by use of the training vessel "Seisui-maru" of Mie University (Table 1). I present the results of the observed temperature and salinity in this paper, as a Part I of this study. As for the velocity fields, I will present it in Part II (SEKINE, 2001) of this paper.

2. Observations

In six observations (Table 1), temperature and salinity were observed mainly by CTD. Accuracy of temperature and salinity is 0.01℃ and 0.05 psu, respectively, the latter of which is checked by the salinometer (Model 601 MKIII).

Main paths of the Kuroshio during the observational periods are shown in Fig. 2. A small Kuroshio meander off Kyushu was formed in July 1989, while the Kuroshio path was located relatively far from the seamount in the other

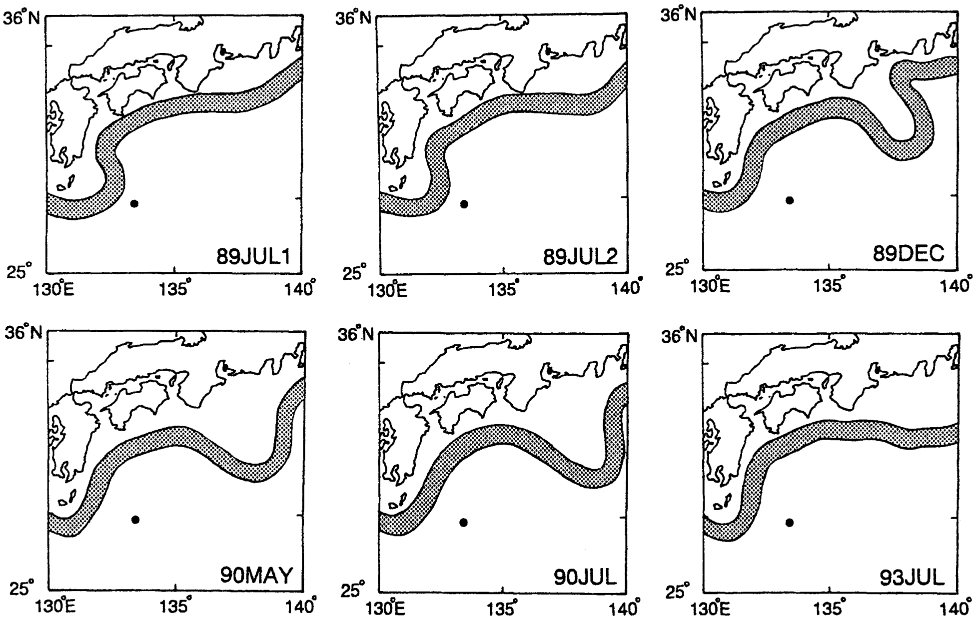

Fig. 2. Main Kuroshio path during the six observation basing on the Prompt Report of Oceanic Condition compiled by Maritime Safety Agency (stippled band) and the location of the Komahashi Daini Kaizan (closed mark).

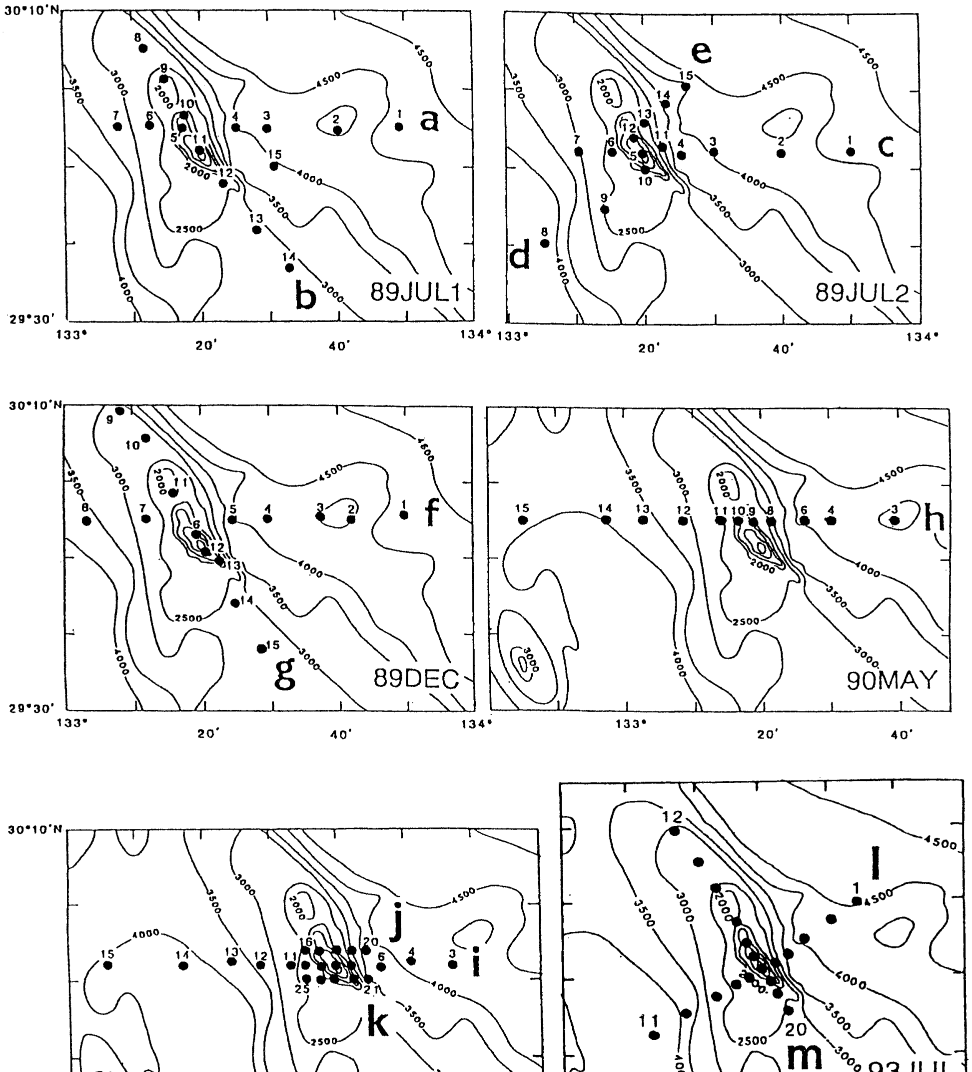

Fig. 3. CTD stations on each cruise. Letters, **a**–**m** identify sections and numbers identify stations.

observational periods. The CTD stations of the six cruises are shown in Fig. 3. KS–89JUL1, KS–89JUL2 and KS–89DEC sections were set NW-SE or NE-SW, parallel or normal to the longer axis of the seamount. In order to observe the background ocean conditions, a longer section was taken for all the observations. Unfortunately, because of CTD and ADCP trouble during KS–90JUL, Mi-com BT (T.S. MICOM-Bathythermograph 400A) by TSURUMI-SEIKI LTD. was used for the temperature observations. The accuracy of Mi-com BT is 0.05℃. Therefore, salinity data were not obtained by this cruise.

3. Results of observations

The vertical distributions of temperature along the sections **a**–**m** are shown in Figs. 4 and

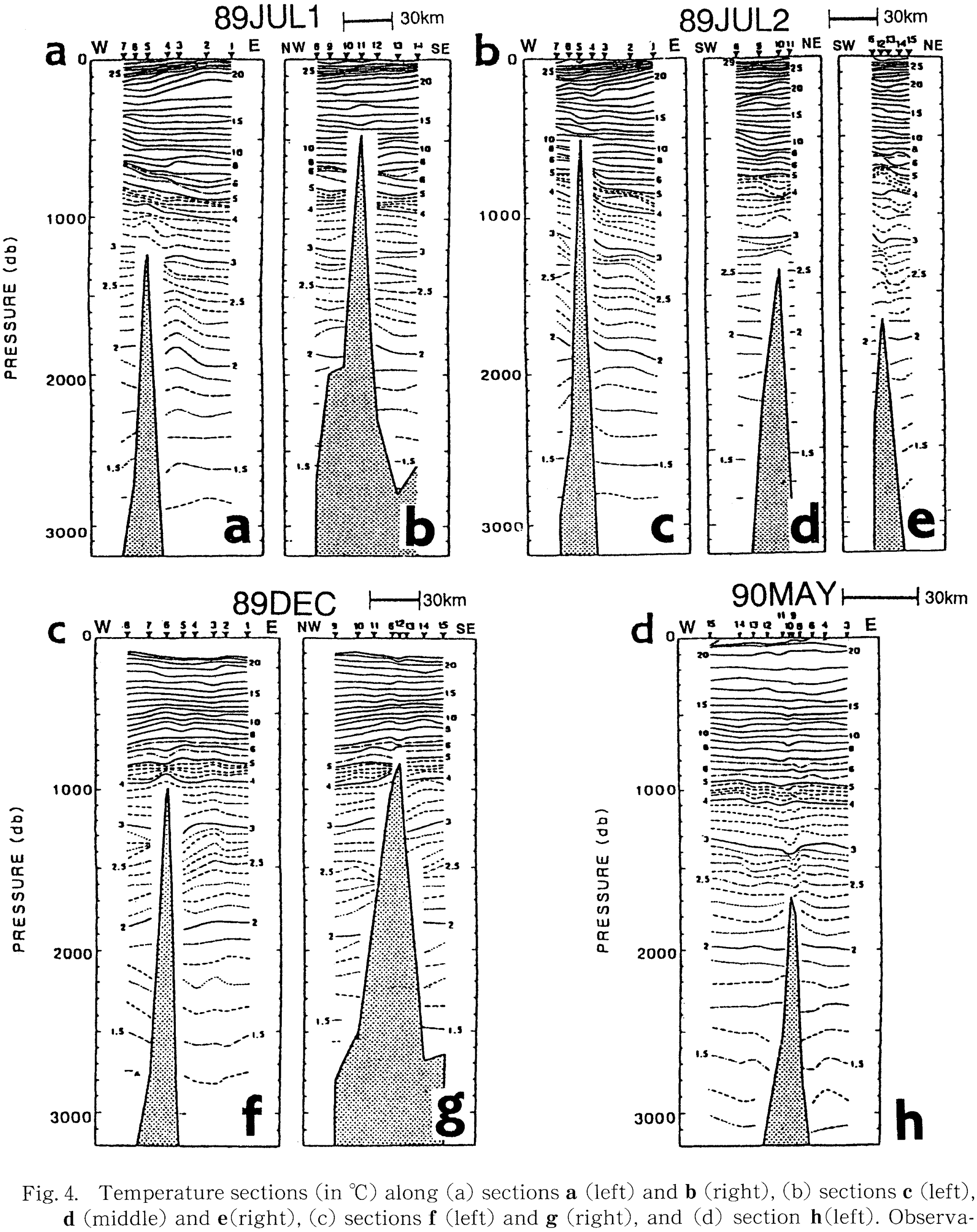

Fig. 4. Temperature sections (in ℃) along (a) sections **a** (left) and **b** (right), (b) sections **c** (left), **d** (middle) and **e**(right), (c) sections **f** (left) and **g** (right), and (d) section **h**(left). Observational section shown in Fig. 3 is shown in right bottom of each panel and observational stations are shown by closed triangles along the top.

5. Along section **a** of KS-89JUL1 (Fig. 4a left), upward shift of the isotherms is seen over the top of the seamount at depths of 850–1100 db. In layer deeper than the top of the seamount, isotherms between 1.7℃ and 2.5℃ show a vertically coherent upward shift in the eastern side of the seamount at depths of 1450–2200 db. In section **b** (Fig. 4a right), the uplift of isotherms over the top of the seamount is unclear: the 15 ℃ isotherm shows a weak downward shift, but the 17℃ isotherm shows an upward shift.

Along section **c** of KS-89JUL2 (Fig. 4b left),

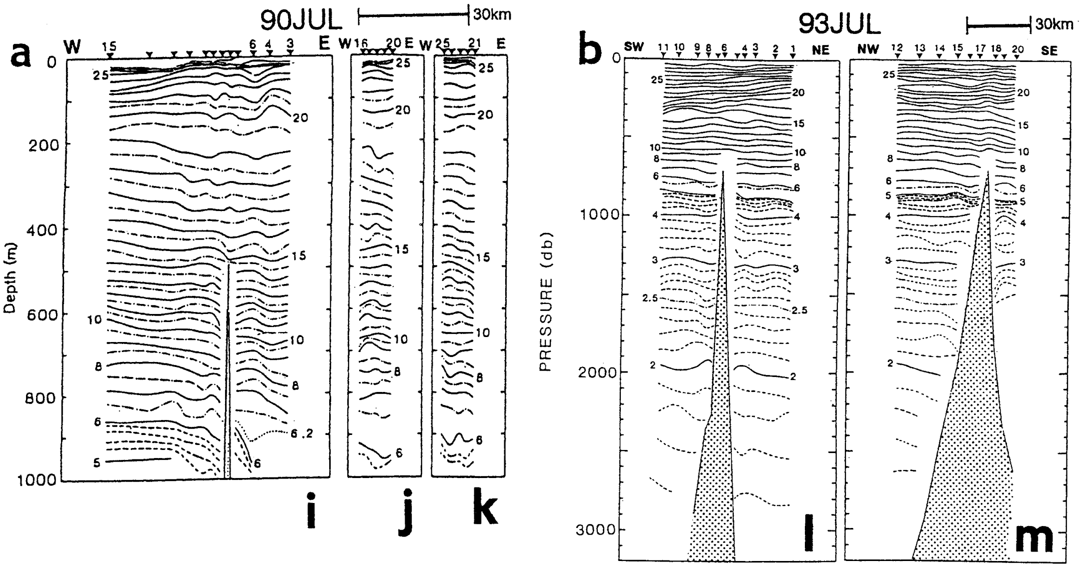

Fig. 5. Temperature sections (in ℃) along (a) sections **i**(left) and **j** (middle) and **k**(right), and (b) sections **l**(left) and **m**(right).

a clear uplift of isotherms is not seen over the seamount. Furthermore, the uplift of isotherms in the eastern side of the seamount observed in KS-89JUL1 (Fig. 4a left) is not observed. Since this observation was carried out in only one week after KS-89JUL1 (Fig. 4a), the temperature distribution over the top of the seamount is changed in a short time. However, the section **c** is located in south of section **a** (Fig. 1), spatial variation may be included. In water deeper than the top of the seamount, the 2-6 ℃ isotherms have a clear horizontal gradient over the eastern side slope. As the strong northward flow is observed in this observational period (Part II), the horizontal gradient of 2-6℃ isotherms are associated with the northward flow of small meander of the Kuroshio. Various vertical shifts of the isotherms are seen along section **d** and **e** (Fig. 4b middle and right).

In section **f** of KS-89DEC (Fig. 4c left), the formation of the mixed layer with a uniform temperature of 21℃ is seen in the surface layer, while seasonal thermocline is formed in the temperature fields in July (Figs. 4ab and 5ab). Isotherms are uplifted over the top of seamount at depths of 850-1000 db. Along section **g** (Fig. 4c right), gap of the depth of isotherm over the side slope between northwestern area and southeastern area is detected. Similar gap is seen in other sections. The gaps of isotherm have been also observed in other seamounts (e.g., FUKASAWA and NAGATA, 1978; SEKINE *et al.*, 1994).

In section **h** of KS-90MAY (Fig. 4d), coherent downward shift of the isotherms is found at depths of 1300-1700 db over the top of the seamount. This coherent downward shift is also seen in the salinity field (Fig. 6d). Some topographic effects of the seamount are suggested in these depths.

In section **i** of KS-90JUL (Fig. 5a left), isotherms are shifted downward at 400-500 db over the top of the seamount. However, the downward shift at 400-500 db is unclear along sections **j** and **k**, which suggests that the downward shift of the isotherms are confined to the top of the seamount. The depth gap of isotherms of 5℃ and 6℃ with different gradient over the side slope is very significant. In section **l** (Fig. 5b left), there is no clear vertical change in isotherms over the top of the seamount, while a relatively coherent weak upward shift of isotherms is detected along section **m**. Vertical shifts of the isotherms are seen at both sides of the seamount, however, their

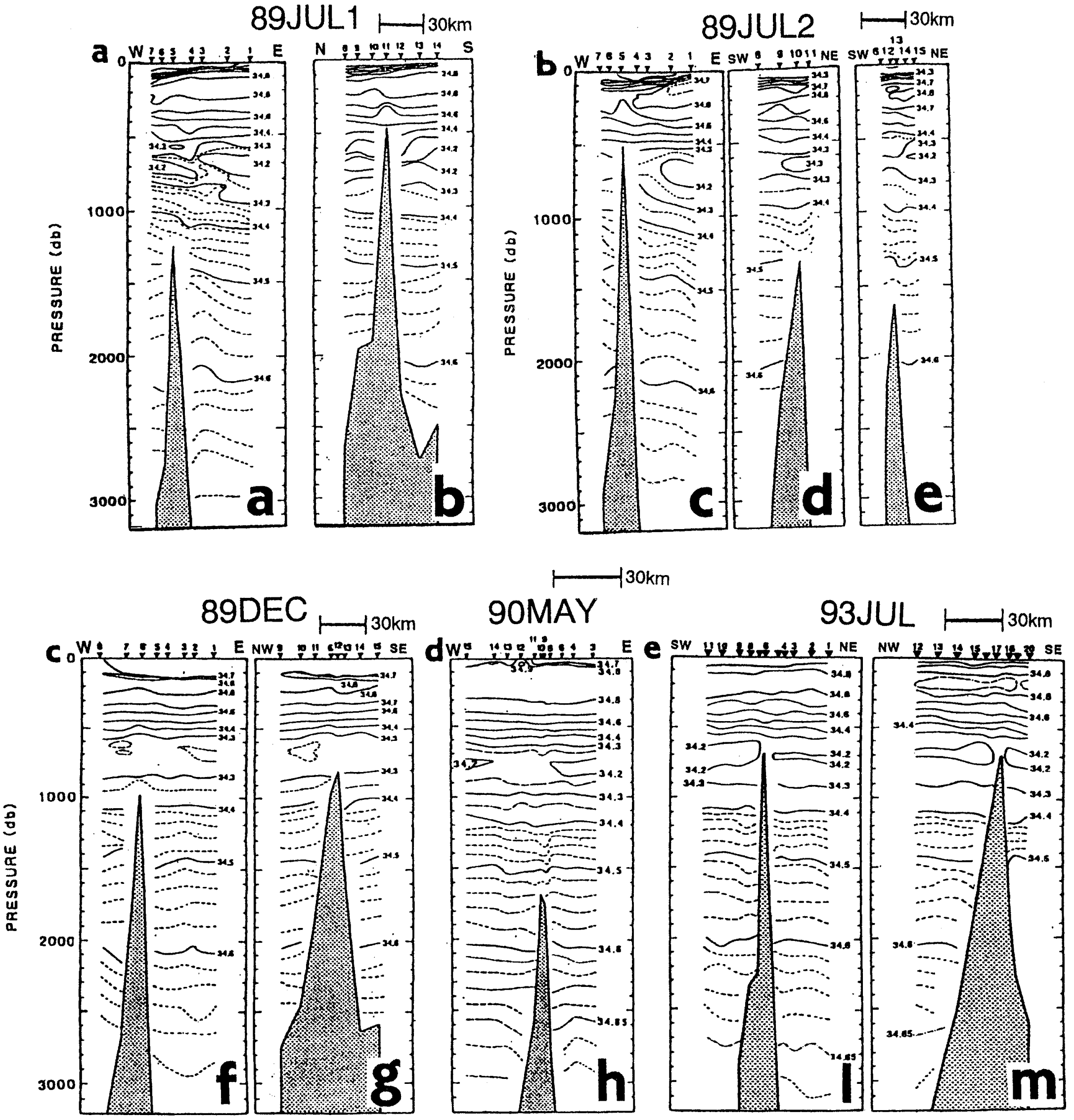

Fig. 6. Salinity sections (in psu) along (a) sections **a** (left) and **b** (right), (b) sections **c** (left), **d** (middle) and **e**(right), (c) sections **f** (left) and **g** (right), (d) section **h**(left) and (e) sections **l** (left) and **m**(right). Stations are shown by closed triangles along the top.

gradients are not confined to one specified direction to the bottom topography of the seamount.

The observed salinity fields are shown in Fig. 6. A salinity minimum water is commonly observed at depths 700–800 db. The salinity minimum corresponds to the North Pacific Intermediate Water (NPIW), which comes from east of the Izu Ridge to the Shikoku Basin (e.g., REID, 1965; YASUDA *et al.*, 1996; SEKINE *et al.*, 2000). In section **a** of KS-89JUL1, the salinity minimum layer (34.2 psu) is unclear over the top of seamount. Isohalines at depths of 1500–2200 db are shifted upward in the eastern side of the seamount, of which change are similar to those of the isotherms shown in Fig. 4a. The

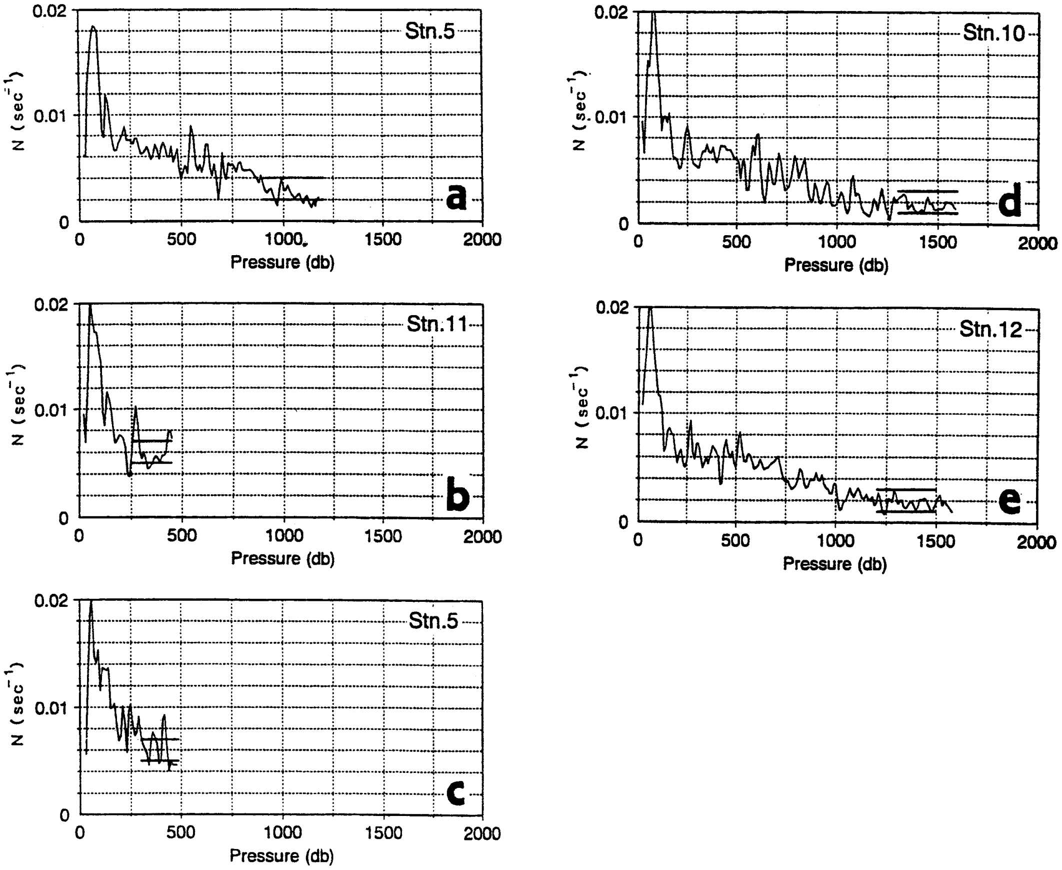

Fig. 7. Vertical distribution of Brunt-Väisälä frequency at the stations shown in the right top of each panel with shallowest depth in each observational line. (a) St. 5 of the observational line **a** in KS-89JUL1, (b) St. 11 of **b** in KS-89JUL1, (c) St. 5 of **c** in KS-89JUL2, (d) St. 10 of **d** in KS-89JUL2, (e) St. 12 of **e** in KS-89JUL2, (f) St. 6 of **f** in KS-89DEC, (g) St. 12 of **g** in KS-89DEC, (h) St. 9 of **h** in KS-90MAY, (i) St. 6 of **l** in KS-93JUL and (j) St. 17 of **m** in KS-93JUL.

similar change to temperature is also seen in Fig. 4b, in which changes associated with the approach of small meander of the Kuroshio is detected. Although the vertical shifts of the isohalines similar to those of isotherms are detected in most of other sections, the salimity minimum formed by NPIW is a characteristic phenomena and its distribuion gives new inflormation which is not seen in the temperature fields. Therefore, we focus on the change in the salinity minimum layer of NPIW over the seamount in the following.

It should be noted that less saline water less than 34.25 psu does not exist just above the top of the seamount (Fig. 6 bcde). In particular, clear salinity minimum water less than 34.2 psu is detected in the western and eastern side of the seamount (Fig. 6e), but such a less saline water is not seen over the top the seamount. These common features suggest that the unclear salinity minimum over the top of the seamount is caused by enhanced vertical mixing over the top of the seamount by the internal wave generated by the seamount and/or by the topographic effect of the seamount, which forces a less salinity water to flow along isopleths of depth around the top of the seamount. Unclear less saline water (NPIW) over the top of the seamount is also observed over the Daini Kinan Kaizan (SEKINE and HAYASHI, 1992) and Tosa-Bae (SEKINE, *et al.*, 1994).

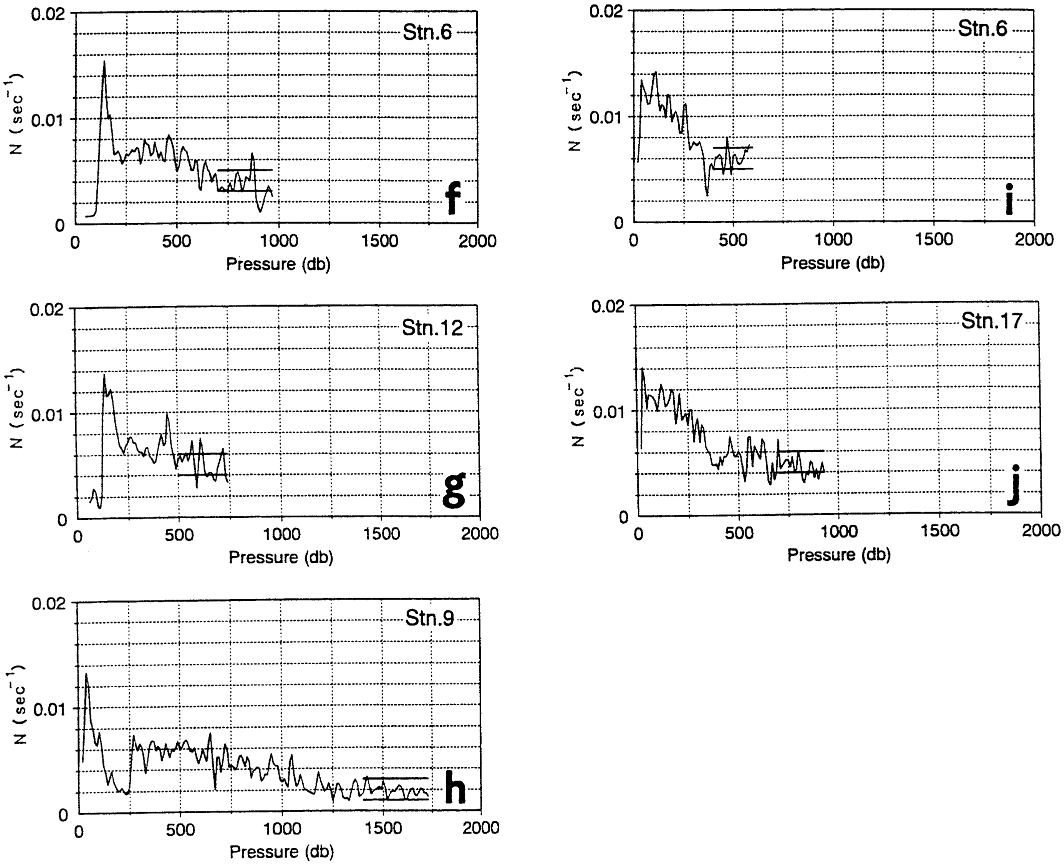

Fig. 7. (f) St. 6 of **f** in KS-89DEC, (g) St. 12 of **g** in KS-89DEC, (h) St. 9 of **h** in KS-90MAY, (i) St. 6 of **l** in KS-93JUL and (j) St. 17 of **m** in KS-93JUL.

4. Topographic effect of the Komahashi Daini Kaizan

If we assume constant Brunt-Väisälä frequency (N) and "bell-shaped" seamount with a height of $h_0/(1+(x/L)^2)$, where h_0 is a peak height and x the horizontal distance from the peak of the seamount and L half of the representative horizontal scale of the seamount, the topographic effect of a seamount is well estimated by the Rossby height (fL/N), where f is the Coriolis parameter (e.g., GILL, 1982). Although these conditions are not exactly fulfilled in the present case, we can estimated the possible range of Rossby height by considering the possible maximum and minimum value of N and L. Vertical distribution of the observed N over the top of the seamount is shown in Fig. 7, in which approximated range of N used in the estimation is also shown. It is shown from Fig. 7 that N is large in the seasonal thermocline layer near the sea surface and N becomes small below the permanent thermocline layer where we set the variable range of N.

Assuming the maximum and minimum L as in Table 2, the estimated Rossby height (RH) and the height of the observed baroclinic Taylor column (HT) are shown in Fig. 8. Here, only coherent or evanescent vertical changes in the observed temperature from the bottom topographies are considered in the evaluation of observed HT, while those of which maximum vertical displacement is separating from the bottom topographies of the seamount are neglected. It is shown from Fig. 8 that RH varies significantly, depending on the estimated L and N. Although positive correlation is detec-

Table 2. Estimated Rossby height (RH $= fL/N$)

Cruise name	Observational line	N (sec^{-1})	L(km) Mimimum	L(km) Maximum	RH(Rossby height)(m) Minimum	RH(Rossby height)(m) Maximum
KS-89JUL1	**a**	2×10^{-3}	2.7	4.5	97	162
		3×10^{-3}			65	108
		4×10^{-3}			49	81
	b	5×10^{-3}	2.7	5.5	39	79
		6×10^{-3}			32	66
		7×10^{-3}			28	57
KS-89JUL2	**c**	5×10^{-3}	2.0	3.8	29	55
		6×10^{-3}			24	46
		7×10^{-3}			21	39
	d	1×10^{-3}	3.9	7.5	280	540
		2×10^{-3}			140	270
		3×10^{-3}			94	180
	e	1×10^{-3}	3.0	6.0	216	432
		2×10^{-3}			108	216
		3×10^{-3}			72	144
KS-89DEC	**f**	3×10^{-3}	2.3	4.5	55	108
		4×10^{-3}			41	81
		5×10^{-3}			33	65
	g	4×10^{-3}	6.0	11.3	108	203
		5×10^{-3}			87	163
		6×10^{-3}			72	136
KS-90MAY	**h**	1×10^{-3}	2.7	3.8	194	274
		2×10^{-3}			97	137
		3×10^{-3}			65	91
KS-93JU1	**l**	5×10^{-3}	2.5	3.5	36	50
		6×10^{-3}			30	42
		7×10^{-3}			26	36
	m	4×10^{-3}	4.0	7.0	72	126
		5×10^{-3}			58	101
		6×10^{-3}			48	84

ted, they do not exceed the 95% confidence limit ($\gamma = 0.63$). It is resulted from Table 2 that almost of eatimated RH is smaller than the depth of the peak of the seamount (289 m), in which only two maximums ranges exceed the depth of seamount. As for HT, it is clear from Figs. 4, 5 and 6 that the baroclinic Taylor column does not reach to the upper layer. These two results demonstrate that the topographic effect of the Komahashi Daini Kaizan does not reach to the surface.

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 for six times from 1989 to 1993. Main results of the observations are summarized as follows.

(1) A salinity minimum layer of NPIW is observed at depths 700–800 db in all the observations. Over the top of the seamount, the salinity minimum layer is relatively unclear in comparison with that in the surrounding area. It is suggested that salinity minimum water less than 34.2 psu is vertically mixed relatively well by the internal wave over the top of the seamount and/or is forced to flow along

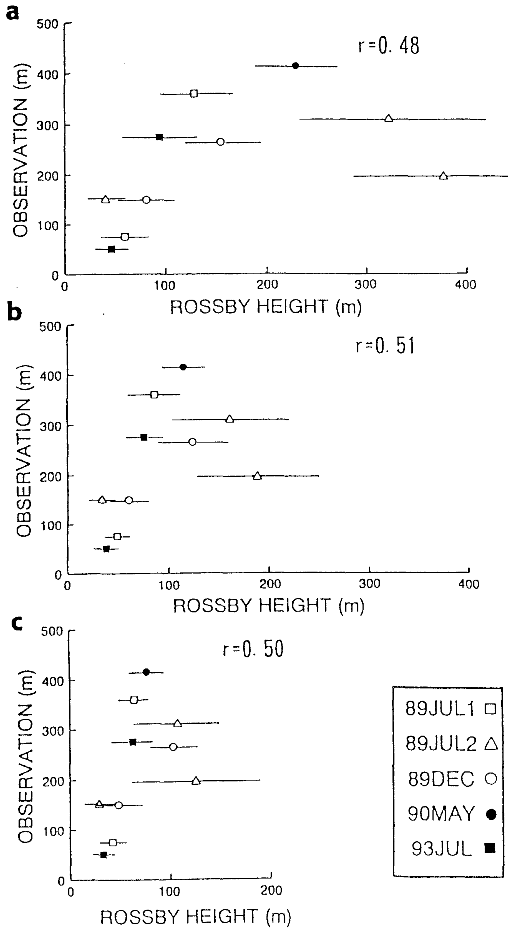

Fig. 8. Correlation between the estimated Rossby height (*fL*/*N*) evaluated from the observed *N* and the observed baroclinic Taylor column estimated from the vertical changes of isotherms and isohalines. (a) Case of minimum possible Brunt-Väisälä frequency (*N*), (b) midrange *N* and (c) maximum possible *N*. Horizontal bars show the possible ranges of Rossby height depending on the representative horizontal scale of the Komahashi Daini Kaizan (*L*).

isopleth of depth of the seamount.

(2) In July 1989, the siginificant change in the temperature and salinity fields are observed during only one week. This is due to the approach of small meander of the Kuroshio generated in southeast of Kyushu. Although the spatial change is included, short period time change is shown to be possible in the vicinity of Komahashi Daini Kaizan.

(3) Although the observed Rossby height (*fL*/*N*) RH varies significantly depending on the estimated *L* and the observed *N*, it is shown that most of eatimated RH is smaller than the depth of the peak of the seamount (289 m). The observed height of baroclinic baroclinic Taylor column (HT) estimated from isotherm and isohaline does not reach to the upper layer. These two facts result that the topographic effect of the Komahashi Daini Kaizan does not reach to the surface.

As is mentioned in (2), significant differences of temperature and salinity fields are observed between KS-89JUL1 and KS-89JUL2 only one week apart. These observational results strongly suggest that more frequent observations are needed to see the detailed oceanic conditions over and around this seamount. It should be also noted that we have no clarified way to filter the contribution of internal wave to the vertical change in the isotherms and isohalines. This problem is more serious in the estimation of the geostrophic flow. Namely, all the vertical change in isotherms are not associated with the geostrophic balance and the contribution of internal waves are not negligible. It is pointed out that some correction which possibly excludes the internal wave is needed for the estimation of geostrophic flow.

Although it is suggested that the topographic effect of the Komahashi Daini Kaizan does not fully reach to the surface (3), the topographic effect on the distribution of the salinity maximum layer denoted in (1) indicates the topographic effect of the seamount reaches to this depth, if a salinity minimum water is forced to flow along isopleth of depth of the seamount. However, if the salinity minimum water is vertically mixed relatively well by the internal wave generated over the top of the seamount, the topographic effect is made through the internal wave, which is different from the effect of the baroclinic Taylor Column. Unfortunately, we can not determine which is more importnant over this seamount. To see this more clearly, non-geostrophic topographic effect of the seamount such as the generation of internal wave should be observed in the future study.

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